# CERES Edition 3 Test Calibration Theory and SSF Results

CERES Instrument Working Group
CERES Science Team Meeting,
Newport News, VA, 04/24/07

Contributors: Norman Loeb, Costy Loukachine, Bruce Wielicki

- Recap on a new climate ERB calibration stability goal and Rev1 Adjustment Results for Terra and Aqua
- Detecting illusive spectral darkening: Stability metrics of DCC albedo and nadir direct compare
- Improved SW darkening model and application to Total channels
- Results of Terra & Aqua Edition 3 Test calibration through SSF inversion and compared to Edition 2
- Summary and thoughts for commentary

Ohring et al (2005) suggests that ERB measurement stability needs to reach 0.3% per decade

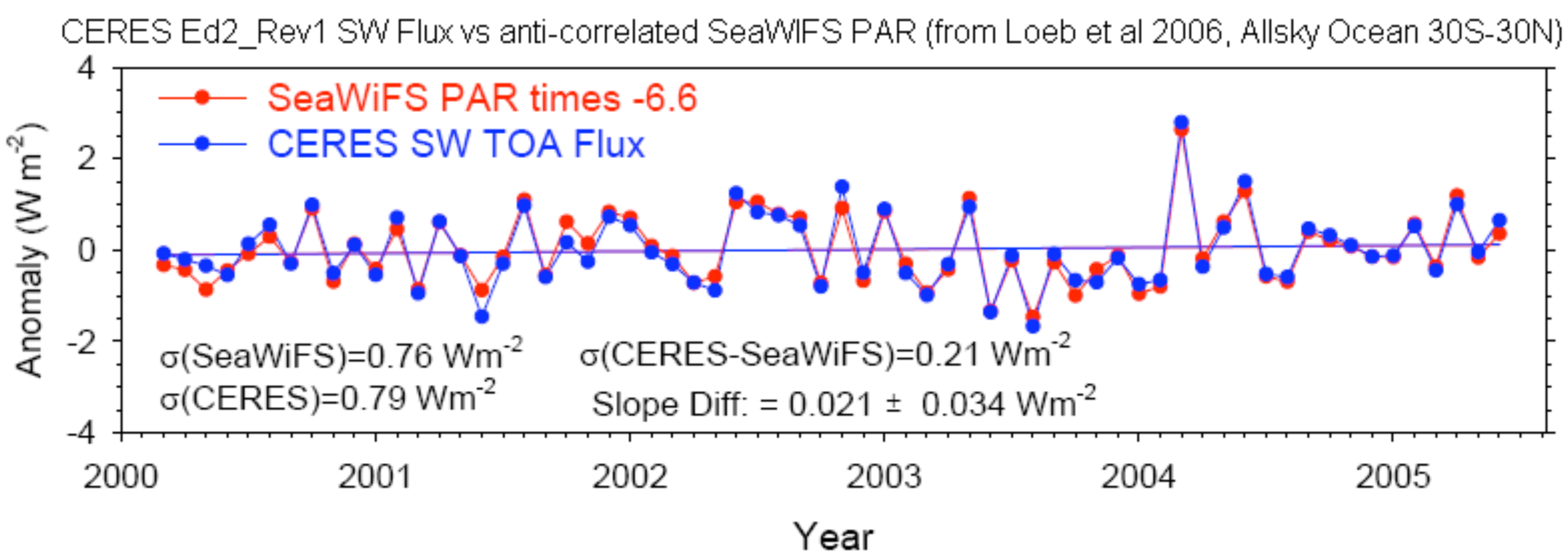

MEETING SUMMARIES

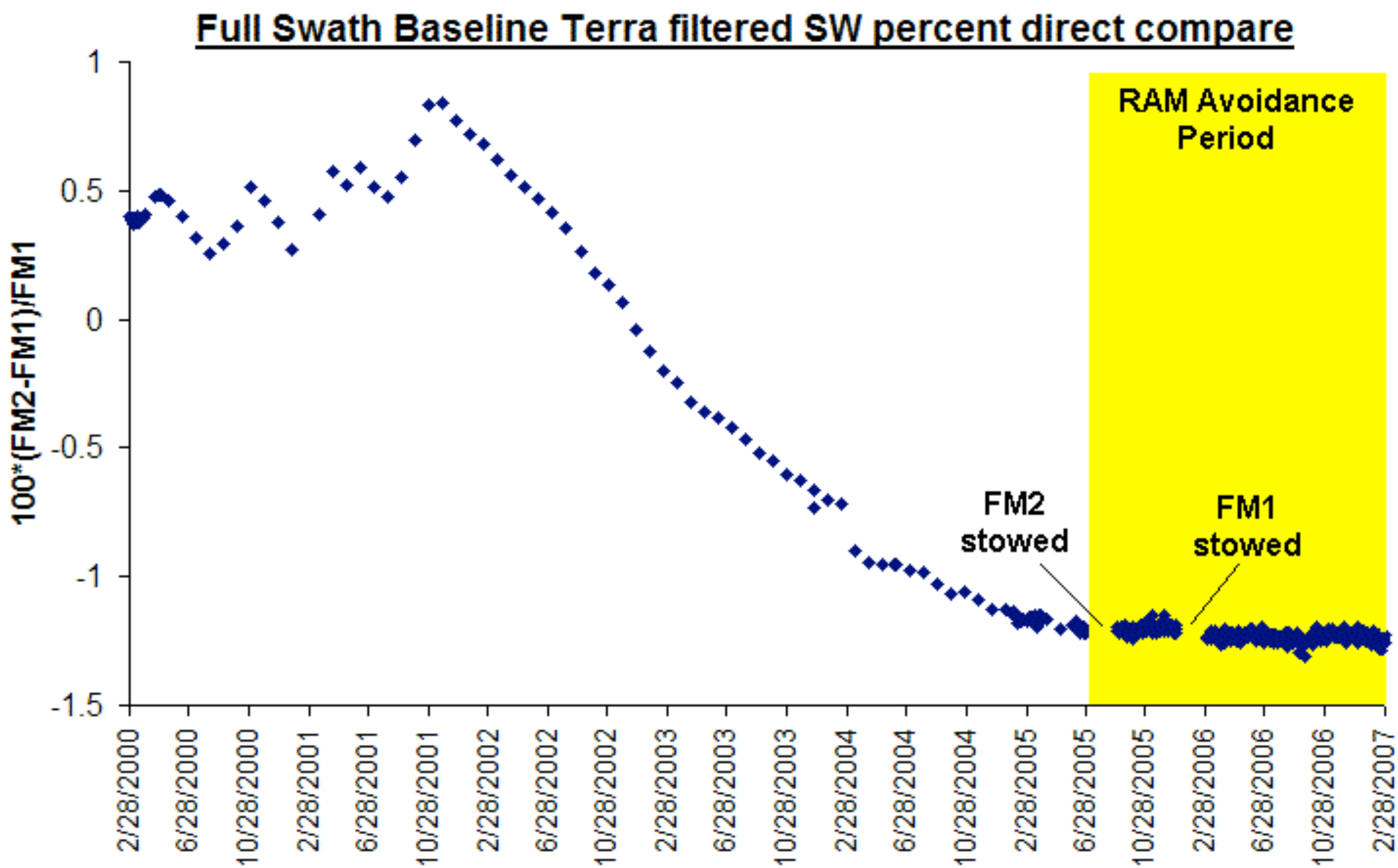
Satellite Instrument Calibration for Measuring Global Climate Change

Report of a Workshop

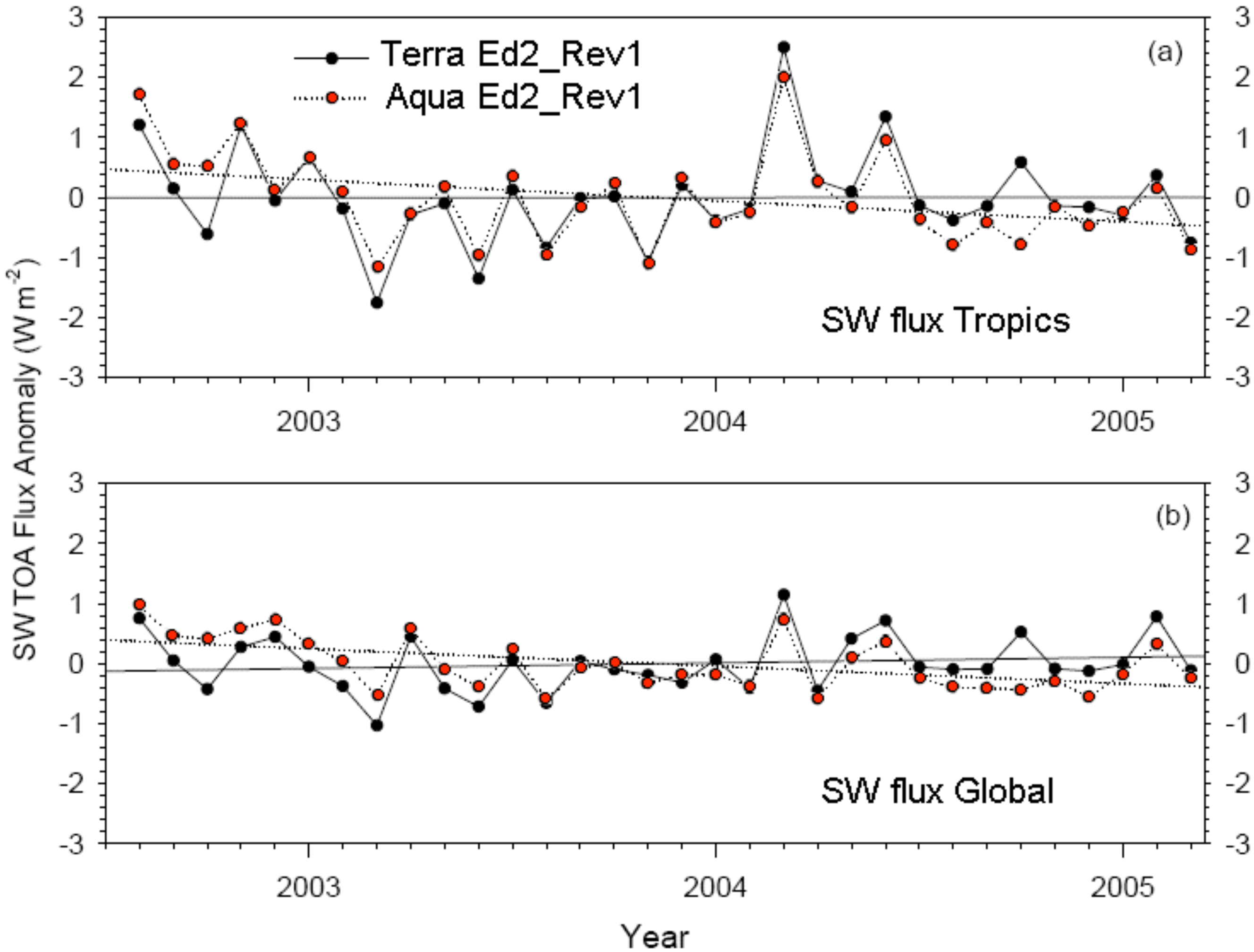
This is near to an order of magnitude greater than CERES instrument design specification stability (note: not data products)

The resulting comparison with anti-correlated SeaWiFS PAR shows that the Rev1 adjustment to CERES Terra SW data yields stability comparable to that of SeaWiFS:




Full Swath Baseline Terra filtered SW percent direct compare
100*(FM2-FM1)/FM1
1
0.5
0
-0.5
-1
-1.5
RAM Avoidance Period
FM2 stowed
FM1 stowed
2/28/2000
6/28/2000
10/28/2000
2/28/2001
6/28/2001
10/28/2001
2/28/2002
6/28/2002
10/28/2002
2/28/2003
6/28/2003
10/28/2003
2/28/2004
6/28/2004
10/28/2004
2/28/2005
6/28/2005
10/28/2005
2/28/2006
6/28/2006
10/28/2006
2/28/2007

However, even after the Rev1 adjustment the Aqua SW flux anomaly continues to drop relative to Terra:

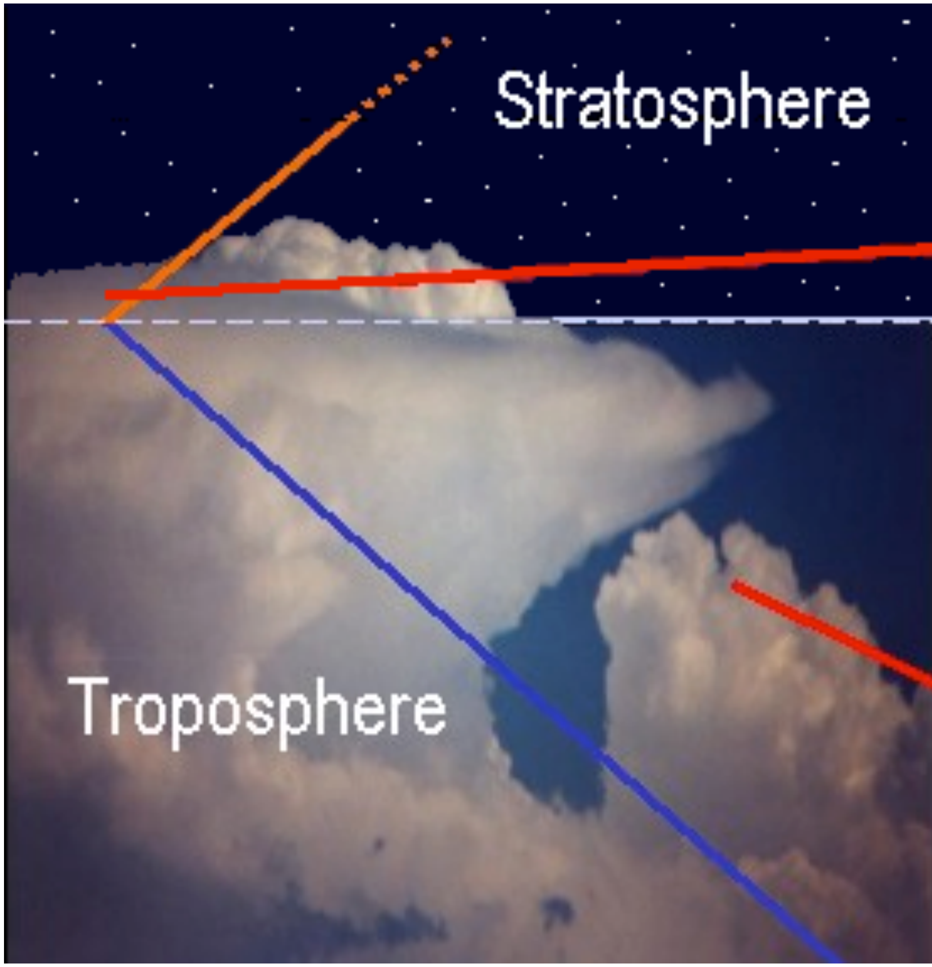


# Examples of Edition 2 Metrics for Stability

# 1. Edition 2 Deep Convective Cloud Albedo

# 2. Edition 2 Un-filtered Direct Compare

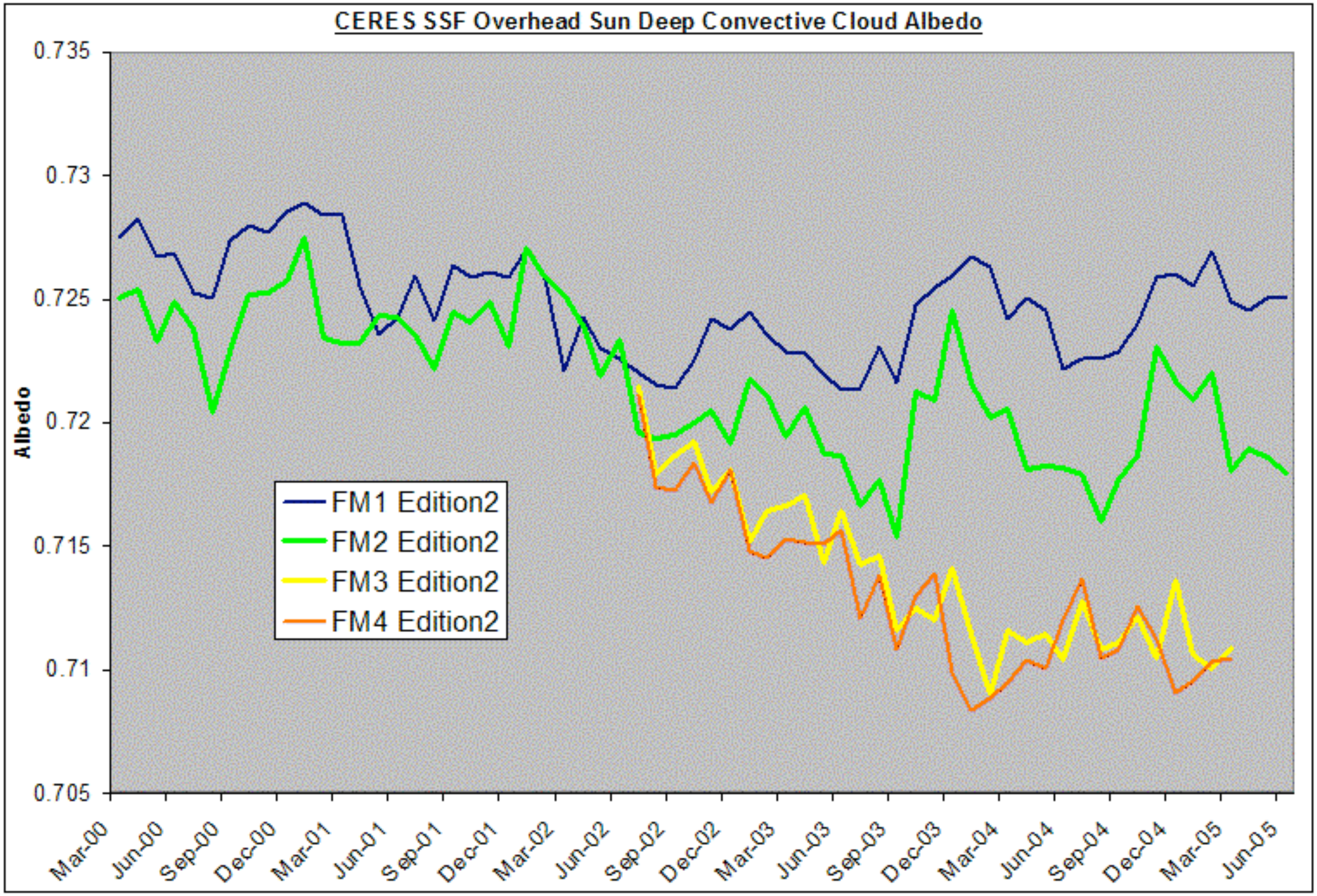
## Use MODIS to find SW footprints of thickest, coldest and most uniform tropical ocean Deep Convective Clouds



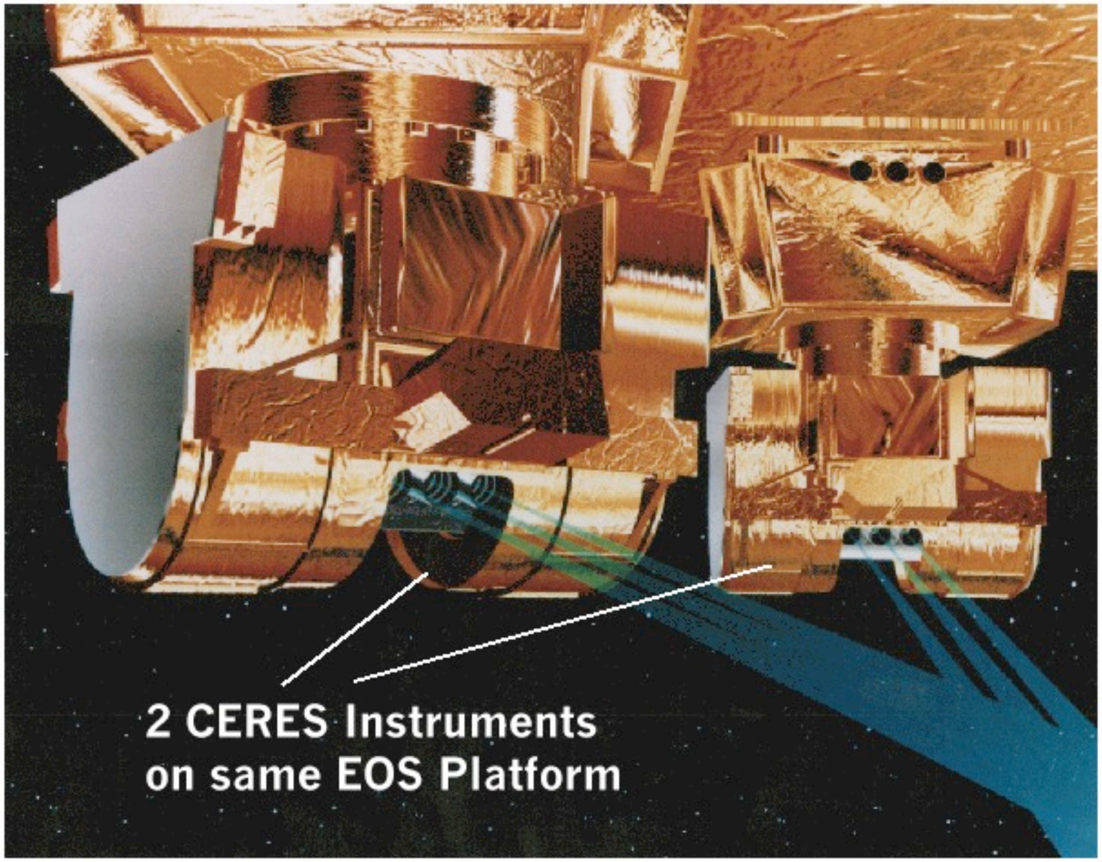

Temp < 205K
Tau > 120
0.6um rad stdev <3%
phase = 2 (ice)
cloud % = 100

latt= +/- 30
IGBP =17 (ocean)

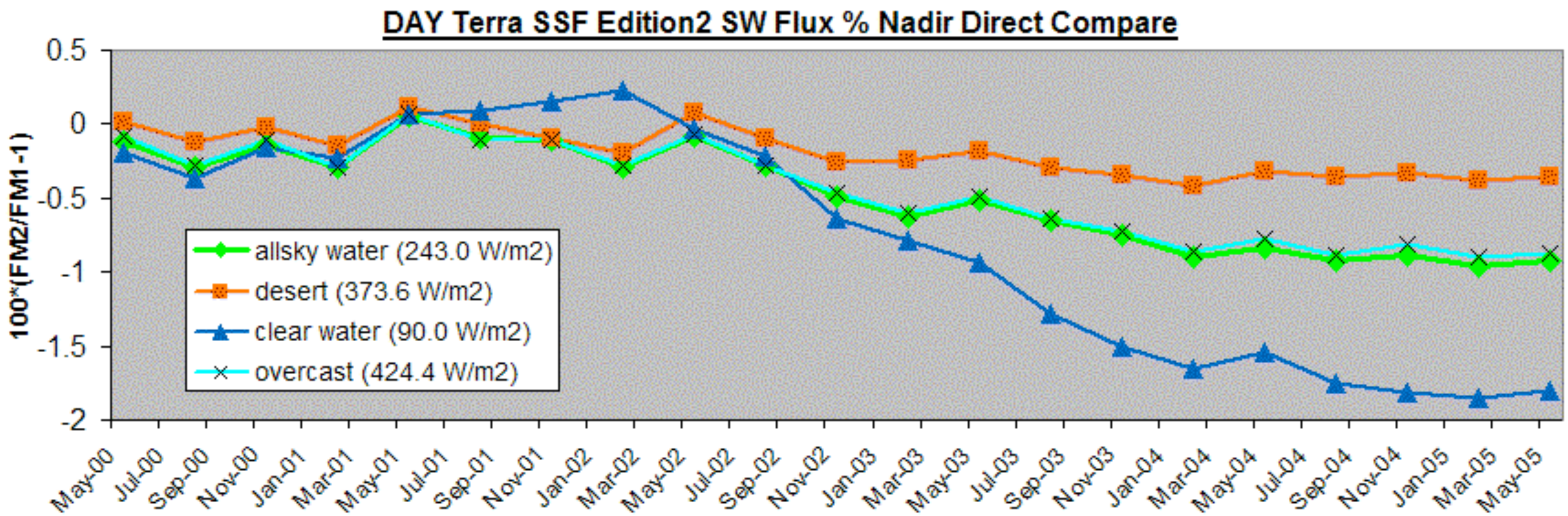
# Edition 2 DCC albedo is a metric for instrument degradation

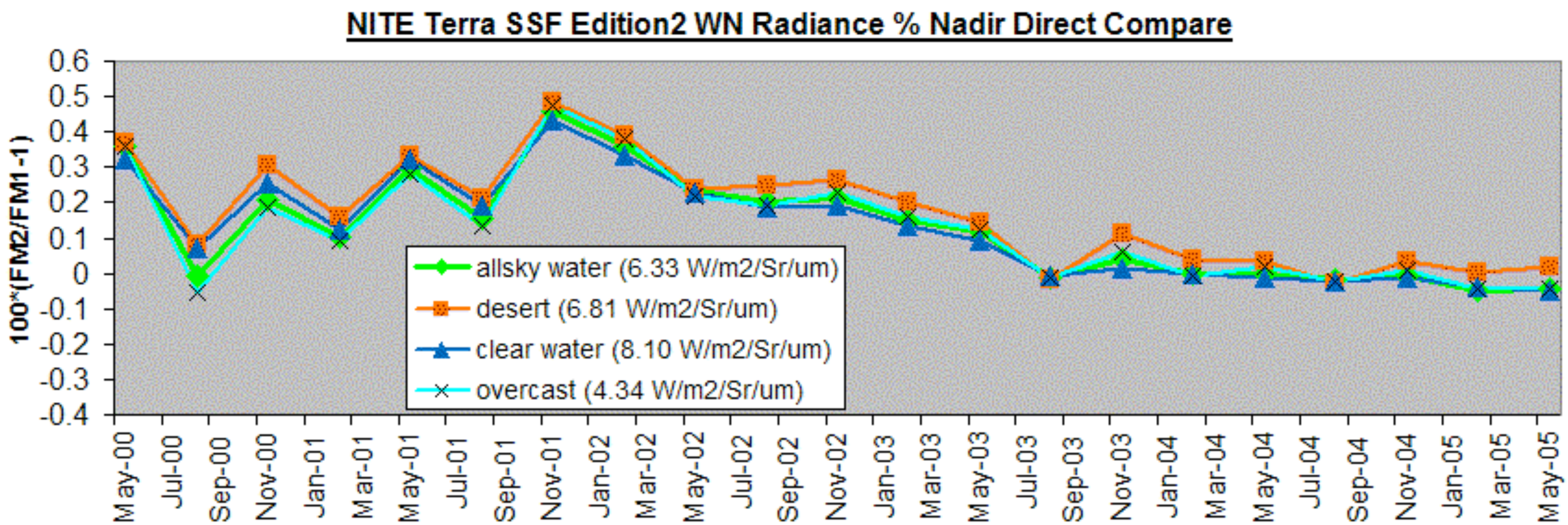


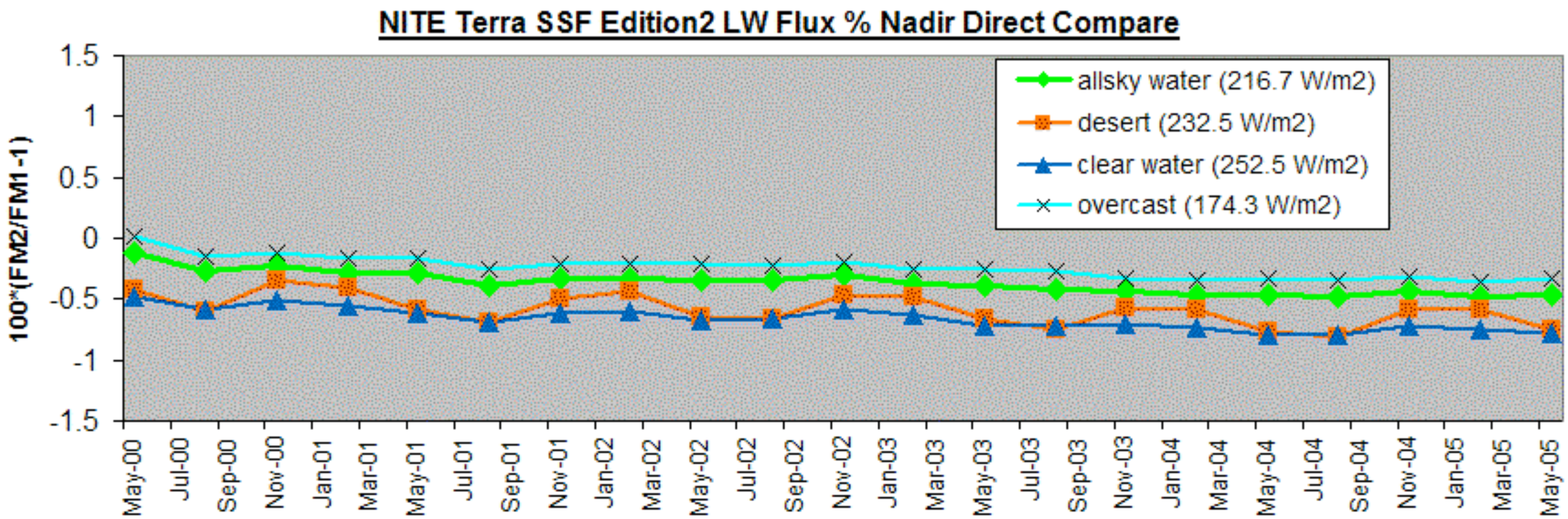
1 RAPS, 1 Xtrack instrument at anytime. Direct Compare (DC) is the ratio of simultaneous nadir un-filtered radiance

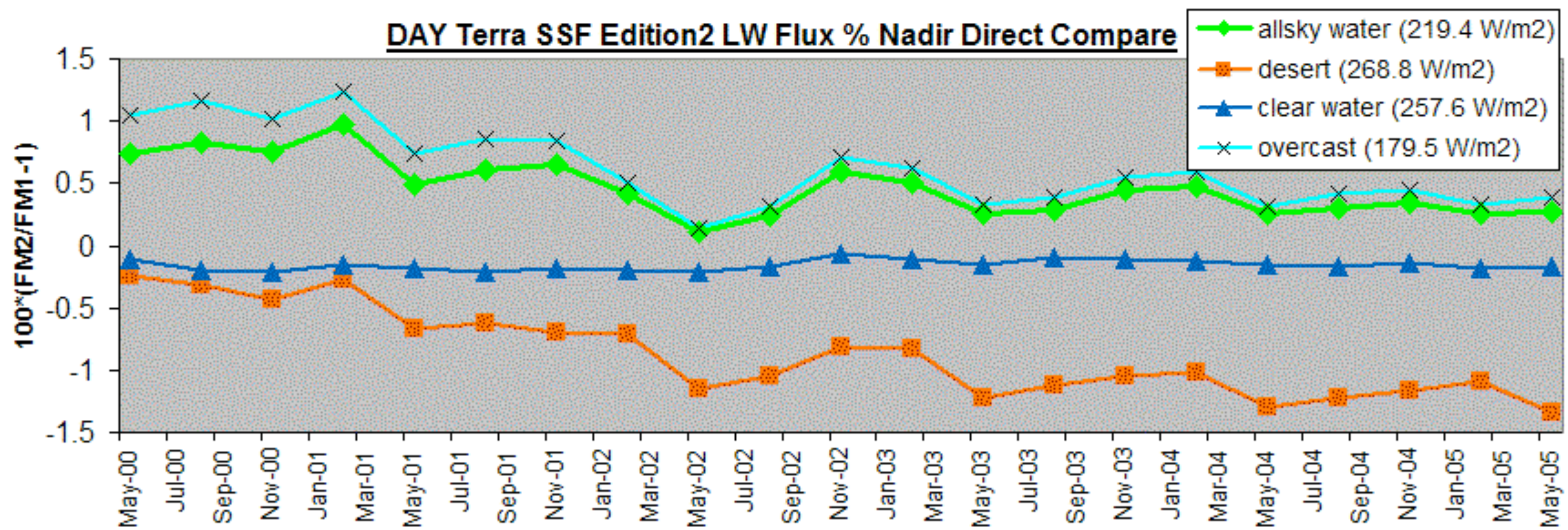


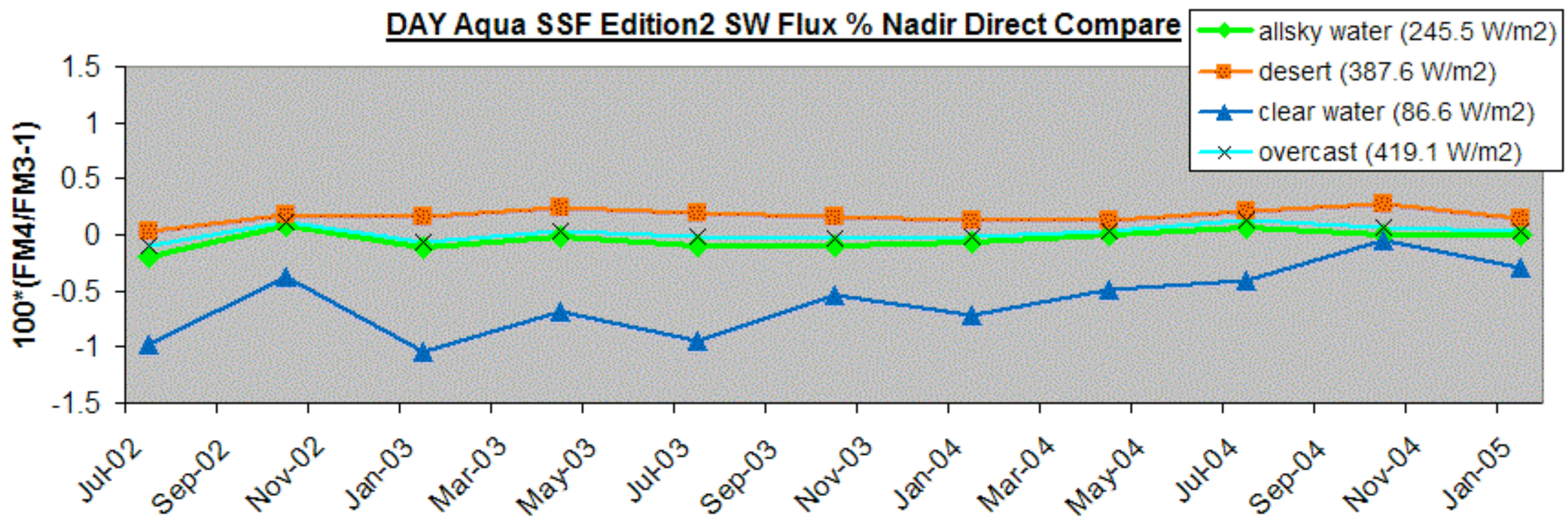

**Instrument diagnostic that is <u>INDEPENDENT OF CLIMATE</u>**

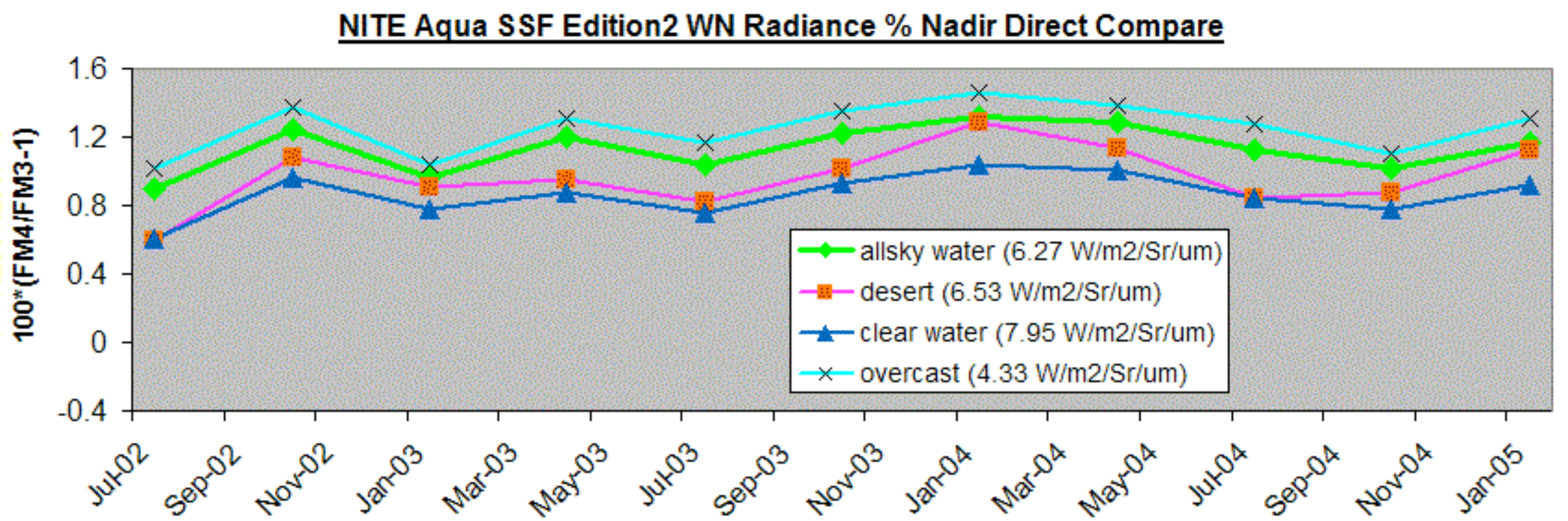

DAY Terra SSF Edition2 SW Flux % Nadir Direct Compare
100*(FM2/FM1-1)
allsky water (243.0 W/m2)
desert (373.6 W/m2)
clear water (90.0 W/m2)
overcast (424.4 W/m2)
0.5
0
-0.5
-1
-1.5
-2
May-00 Jul-00 Sep-00 Nov-00 Jan-01 Mar-01 May-01 Jul-01 Sep-01 Nov-01 Jan-02 Mar-02 May-02 Jul-02 Sep-02 Nov-02 Jan-03 Mar-03 May-03 Jul-03 Sep-03 Nov-03 Jan-04 Mar-04 May-04 Jul-04 Sep-04 Nov-04 Jan-05 Mar-05 May-05

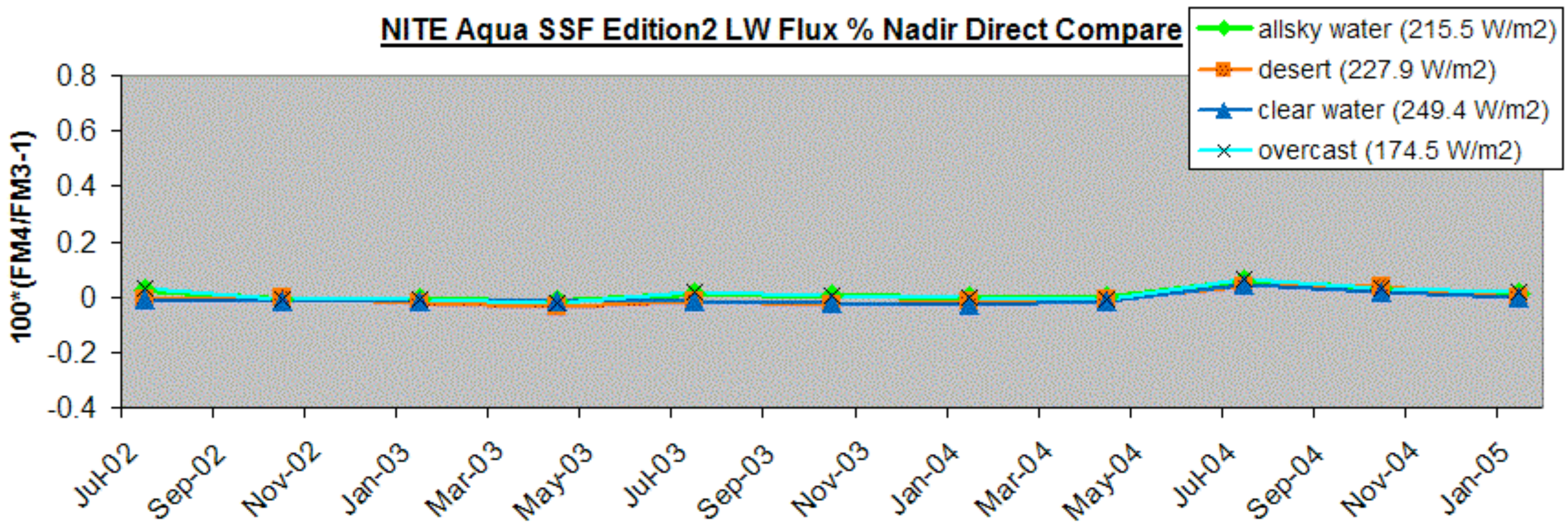

NITE Terra SSF Edition2 WN Radiance % Nadir Direct Compare
100*(FM2/FM1-1)
allsky water (6.33 W/m2/Sr/um)
desert (6.81 W/m2/Sr/um)
clear water (8.10 W/m2/Sr/um)
overcast (4.34 W/m2/Sr/um)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
May-00 Jul-00 Sep-00 Nov-00 Jan-01 Mar-01 May-01 Jul-01 Sep-01 Nov-01 Jan-02 Mar-02 May-02 Jul-02 Sep-02 Nov-02 Jan-03 Mar-03 May-03 Jul-03 Sep-03 Nov-03 Jan-04 Mar-04 May-04 Jul-04 Sep-04 Nov-04 Jan-05 Mar-05 May-05

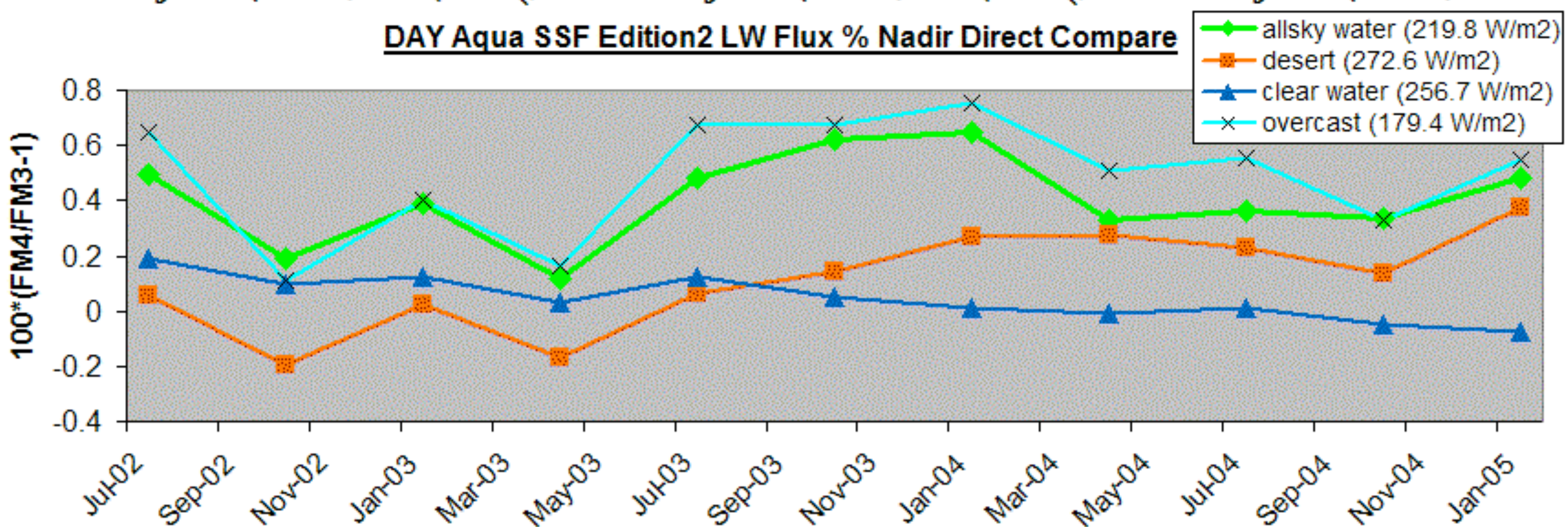

NITE Terra SSF Edition2 LW Flux % Nadir Direct Compare
100*(FM2/FM1-1)
allsky water (216.7 W/m2)
desert (232.5 W/m2)
clear water (252.5 W/m2)
overcast (174.3 W/m2)
1.5
1
0.5
0
-0.5
-1
-1.5
May-00 Jul-00 Sep-00 Nov-00 Jan-01 Mar-01 May-01 Jul-01 Sep-01 Nov-01 Jan-02 Mar-02 May-02 Jul-02 Sep-02 Nov-02 Jan-03 Mar-03 May-03 Jul-03 Sep-03 Nov-03 Jan-04 Mar-04 May-04 Jul-04 Sep-04 Nov-04 Jan-05 Mar-05 May-05


DAY Terra SSF Edition2 LW Flux % Nadir Direct Compare
100*(FM2/FM1-1)
allsky water (219.4 W/m2)
desert (268.8 W/m2)
clear water (257.6 W/m2)
overcast (179.5 W/m2)
1.5
1
0.5
0
-0.5
-1
-1.5
May-00 Jul-00 Sep-00 Nov-00 Jan-01 Mar-01 May-01 Jul-01 Sep-01 Nov-01 Jan-02 Mar-02 May-02 Jul-02 Sep-02 Nov-02 Jan-03 Mar-03 May-03 Jul-03 Sep-03 Nov-03 Jan-04 Mar-04 May-04 Jul-04 Sep-04 Nov-04 Jan-05 Mar-05 May-05


DAY Aqua SSF Edition2 SW Flux % Nadir Direct Compare
allsky water (245.5 W/m2)
desert (387.6 W/m2)
clear water (86.6 W/m2)
overcast (419.1 W/m2)
100*(FM4/FM3-1)
1.5
1
0.5
0
-0.5
-1
-1.5
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05


NITE Aqua SSF Edition2 WN Radiance % Nadir Direct Compare
allsky water (6.27 W/m2/Sr/um)
desert (6.53 W/m2/Sr/um)
clear water (7.95 W/m2/Sr/um)
overcast (4.33 W/m2/Sr/um)
100*(FM4/FM3-1)
1.6
1.2
0.8
0.4
0
-0.4
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05


NITE Aqua SSF Edition2 LW Flux % Nadir Direct Compare
allsky water (215.5 W/m2)
desert (227.9 W/m2)
clear water (249.4 W/m2)
overcast (174.5 W/m2)
100*(FM4/FM3-1)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05


DAY Aqua SSF Edition2 LW Flux % Nadir Direct Compare
allsky water (219.8 W/m2)
desert (272.6 W/m2)
clear water (256.7 W/m2)
overcast (179.4 W/m2)
100*(FM4/FM3-1)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05

# SW Edition 3 calibration

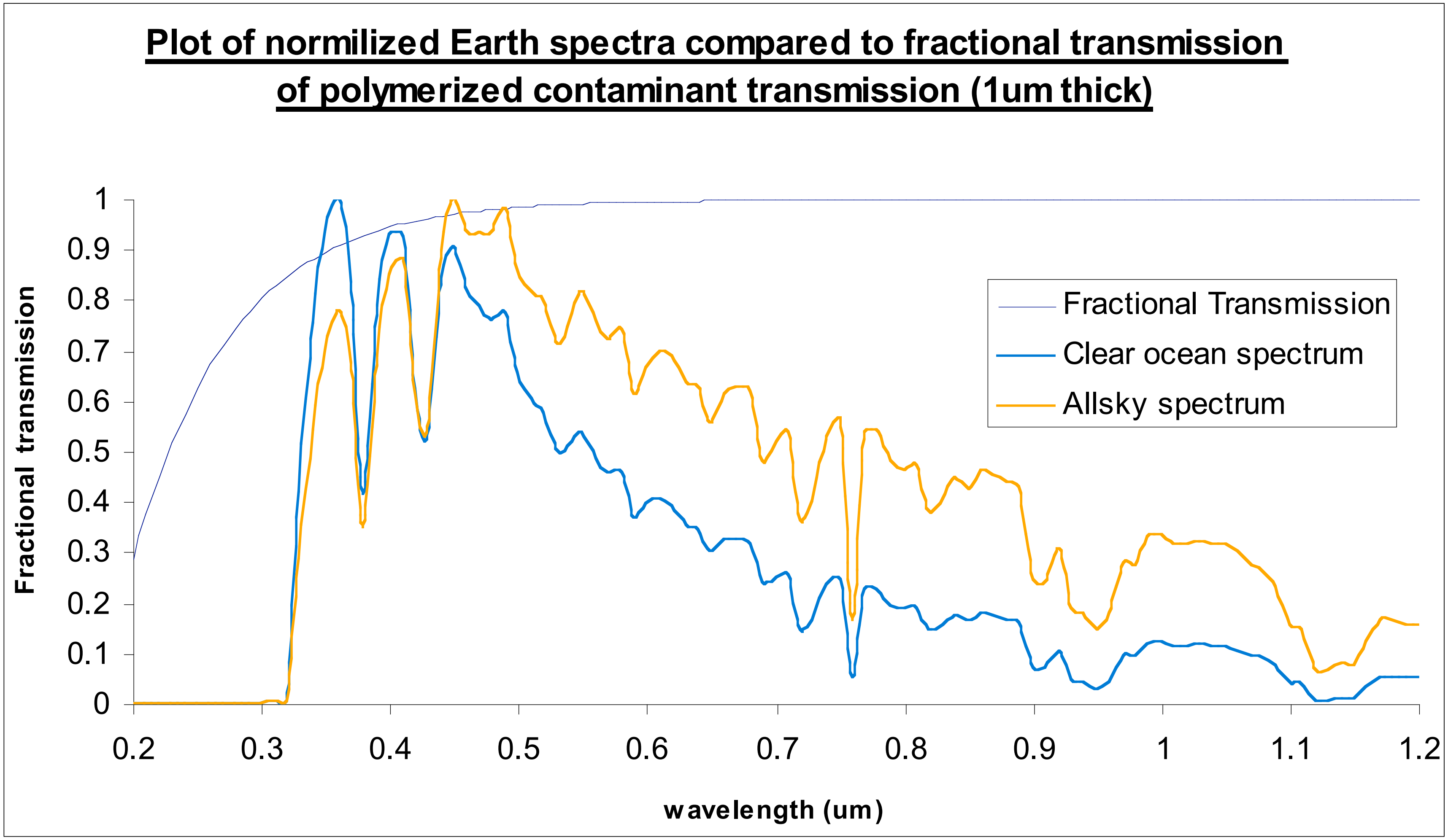
## Model Derived Gains and Spectral response

The deficiencies in the Aqua Rev1 adjustment suggest significant cross-track instrument darkening or on-board lamp drift (< 1%). Hence for Edition 3, a new calibration methodology is needed:

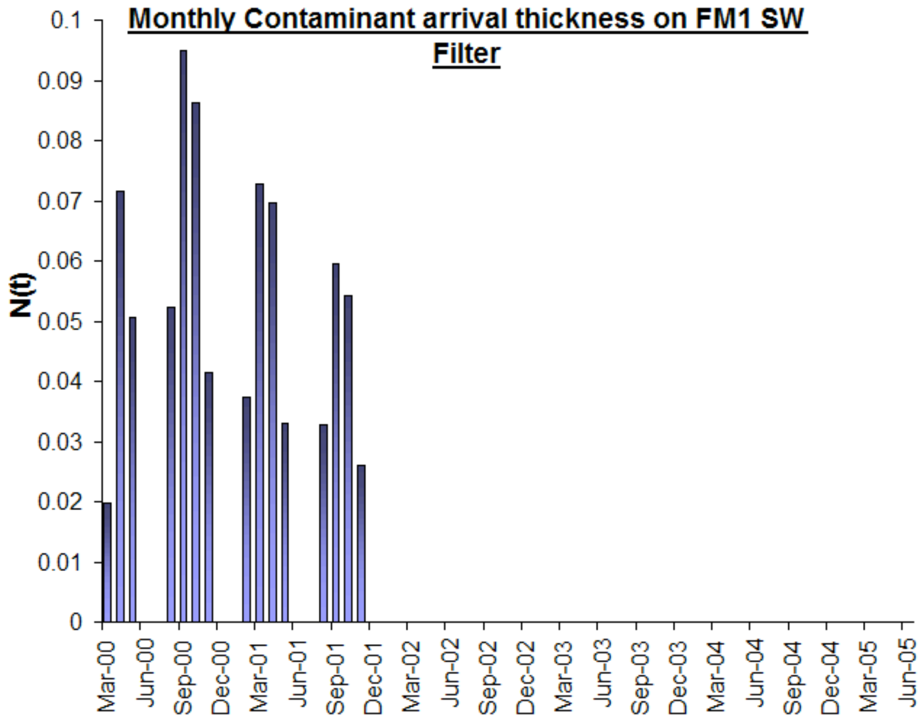
- **Deep Convective Cloud albedo:** Find the albedo of the coldest, brightest and most uniform clouds in the tropics. These become your ‘solar diffuser’ stability metric to replace MAM data.

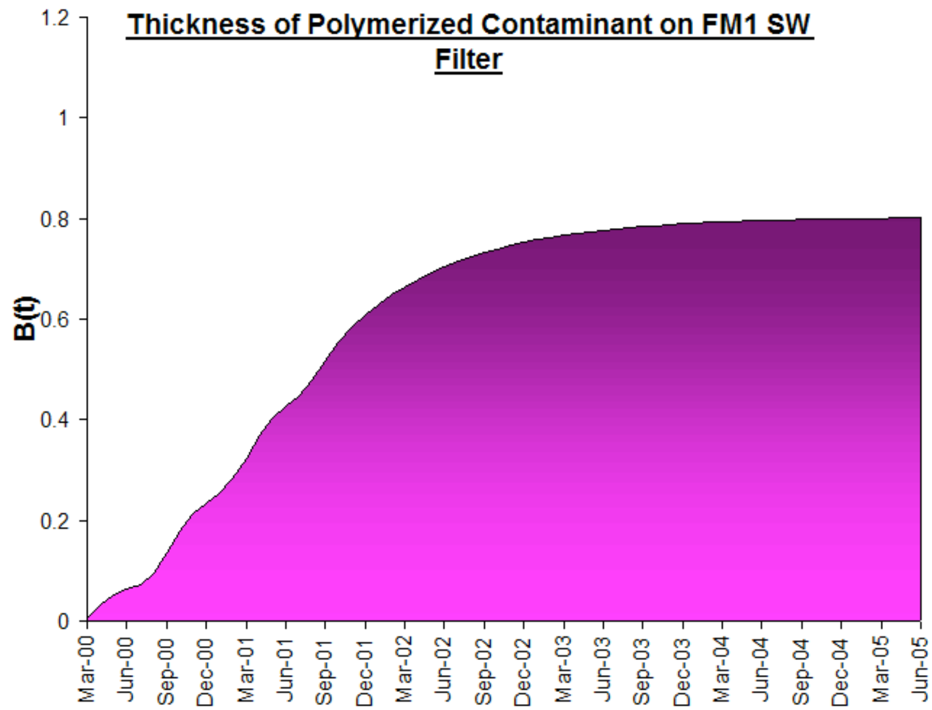
- **Constrain contamination model using direct compare:** Contamination/UV exposure model is adjusted to best match the direct compare of nadir footprints between two instruments on the same platform. Use of clear ocean and allsky scenes allows the model to determine coloration of spectral response changes.

$$D(\lambda) = \left[1 - M.e^{-\alpha\lambda}\right]$$



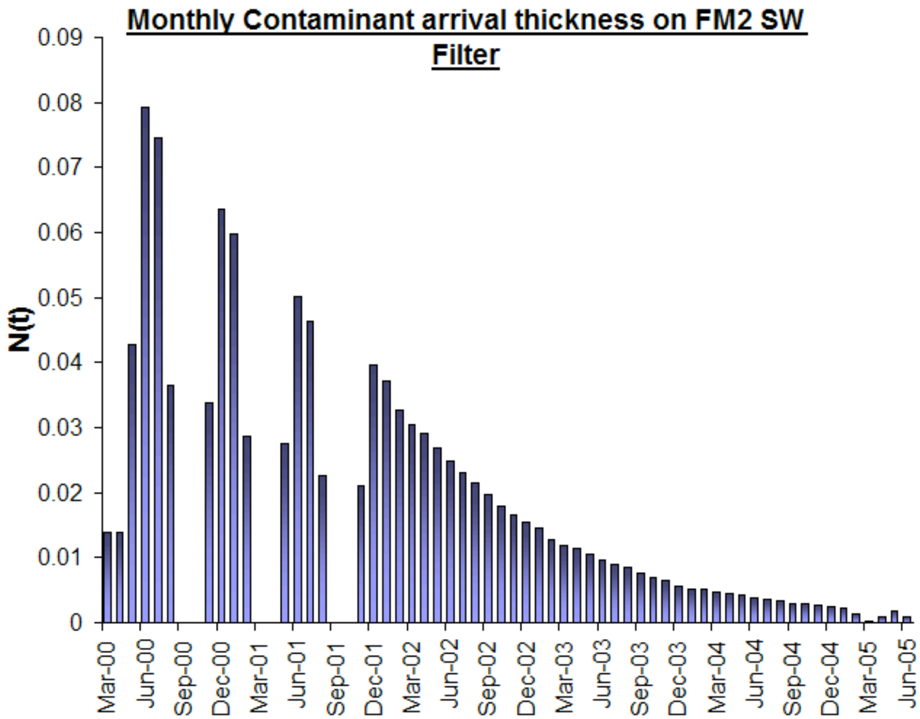
# FM1 Contaminant Thickness

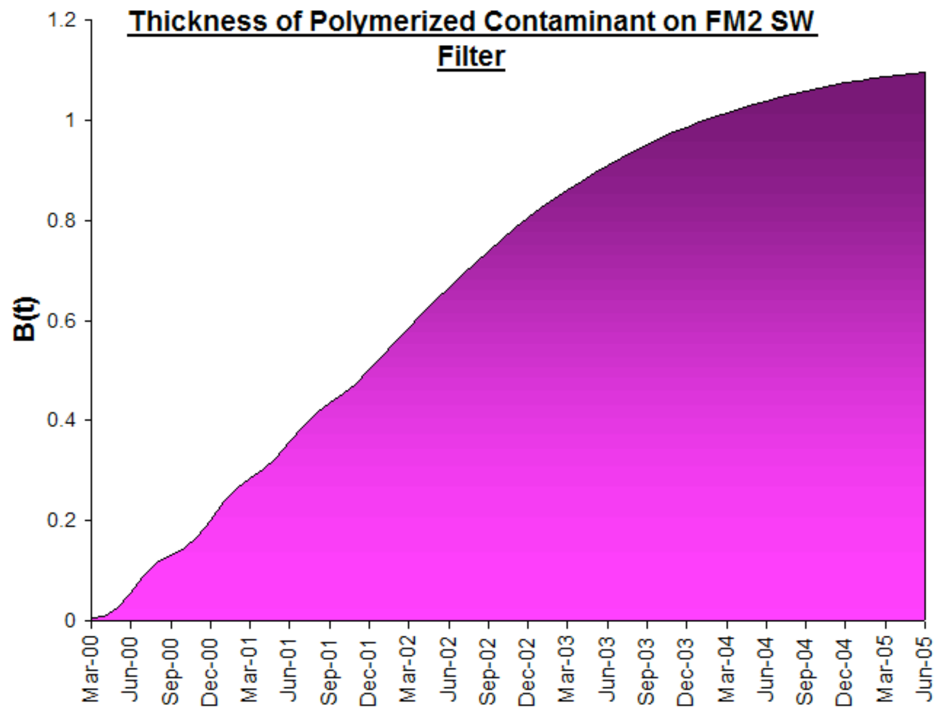



$$\frac{dB(t)}{dt} = \rho\left[\int_0^t N(\xi)d\xi - B(t)\right] + \beta.N(t)$$

# FM2 Contaminant Thickness




$$\frac{dB(t)}{dt} = \rho\left[\int_0^t N(\xi)d\xi - B(t)\right] + \beta.N(t)$$

## Model Spectral Darkening found from contaminant unit transmission and thickness *B(t)*:

$$D(\lambda, t) = \left[1 - M.e^{-\alpha\lambda}\right]^{B(t)}$$

$$S^{ed3}(\lambda, t) = D(\lambda, t) \times S^{Gnd}(\lambda)$$

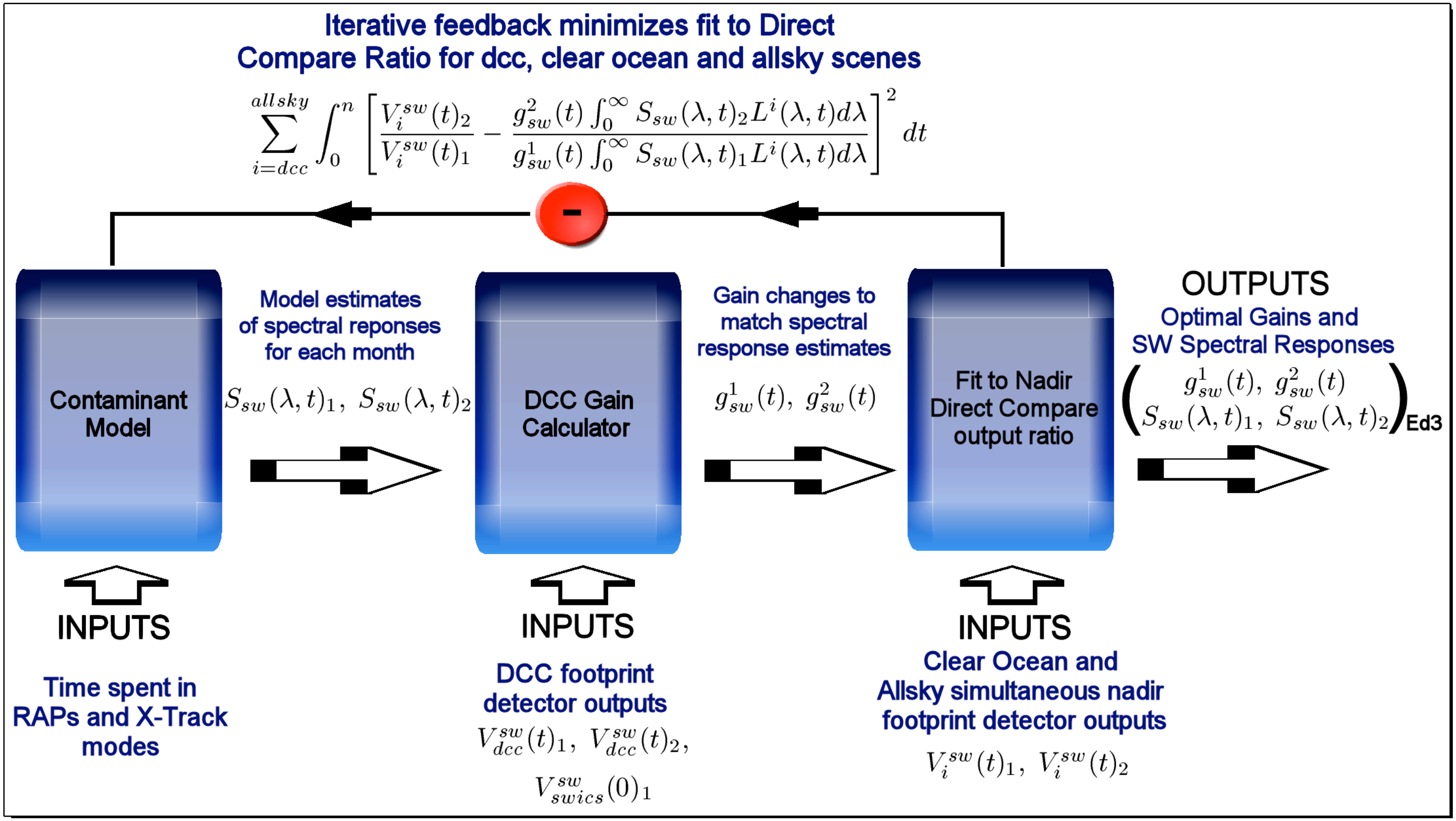
**Detector Output = Gain * Filtered Radiance**

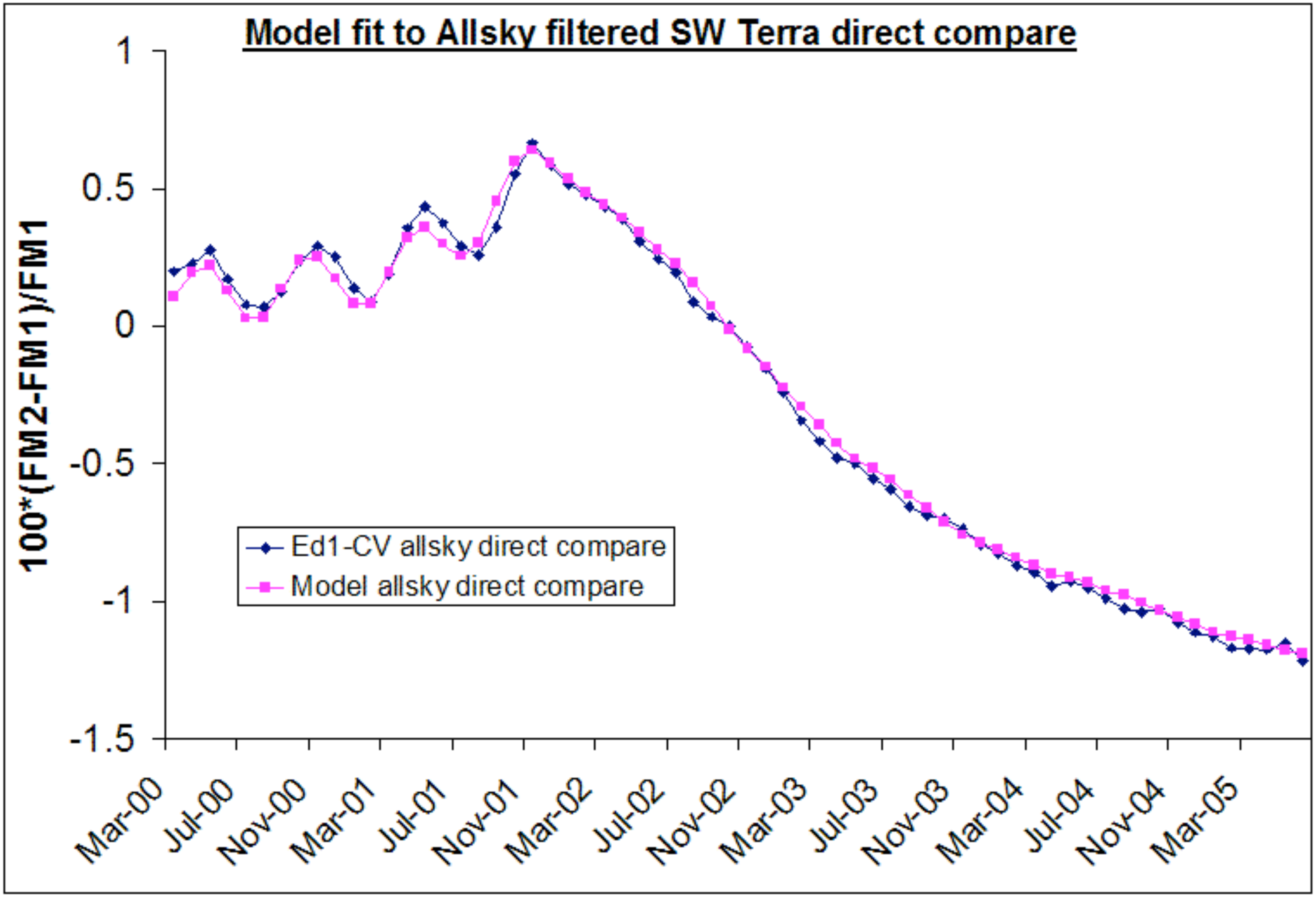
$$V = g \times \int_0^\infty S(\lambda) L(\lambda) d\lambda$$

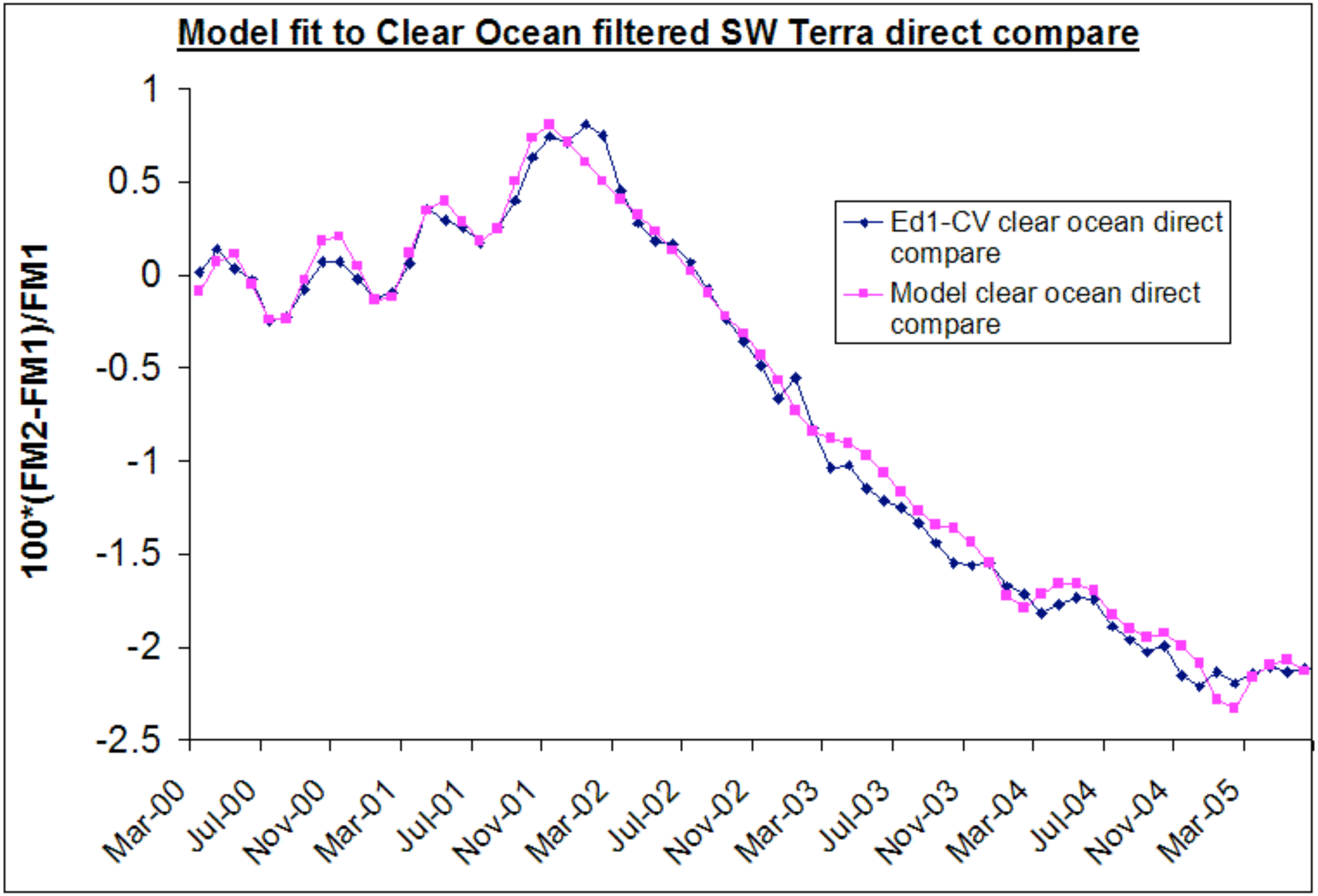
**Hence SW gain changes can be found using the DCC detector signal and modeled filtered radiance:**

$$g_{sw}(t) = \frac{V_{dcc}^{sw}(t)}{\int_0^\infty S_{sw}^{ed3}(\lambda, t) L^{dcc}(\lambda, t) d\lambda}$$

# Run iterative model for all ‘*n*’ months available:

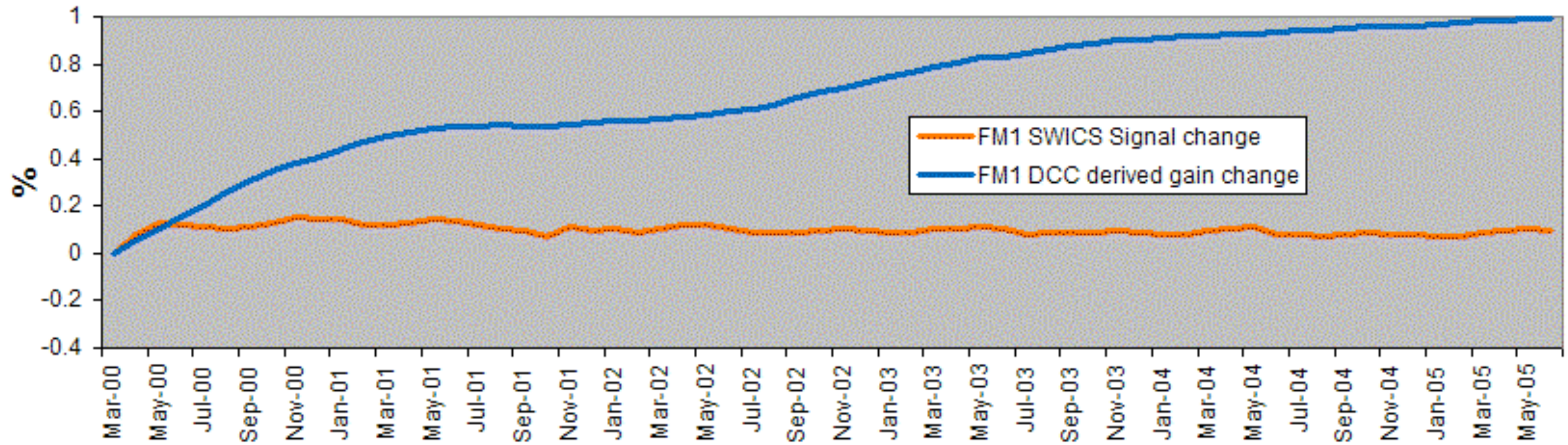


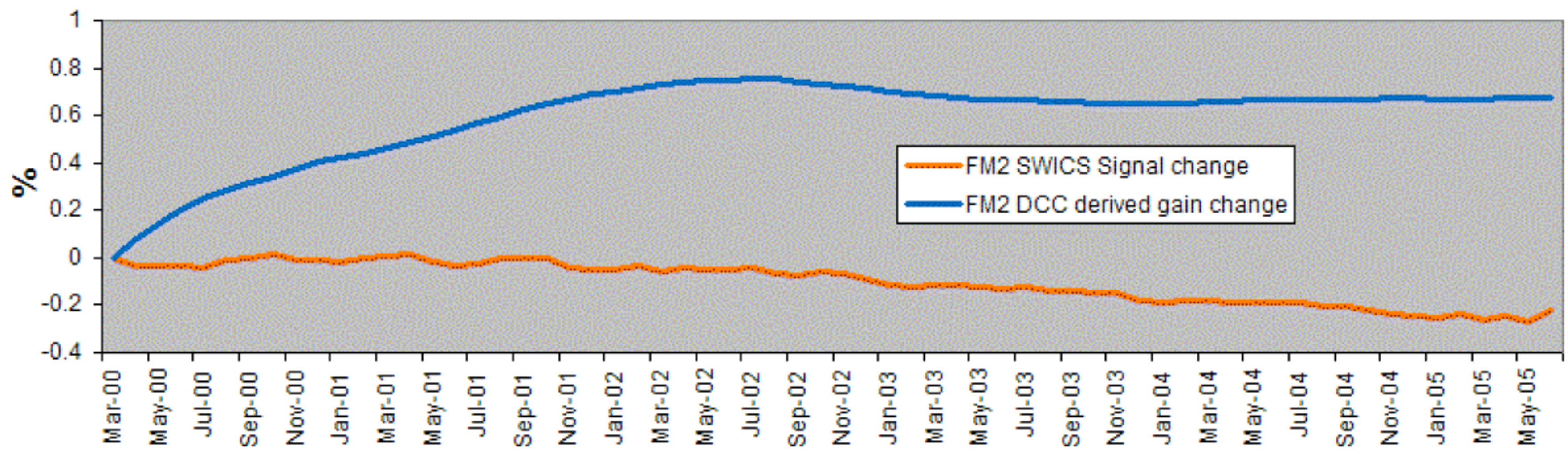

Model fit to Allsky filtered SW Terra direct compare
100*(FM2-FM1)/FM1
1
0.5
0
-0.5
-1
-1.5
Ed1-CV allsky direct compare
Model allsky direct compare
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05



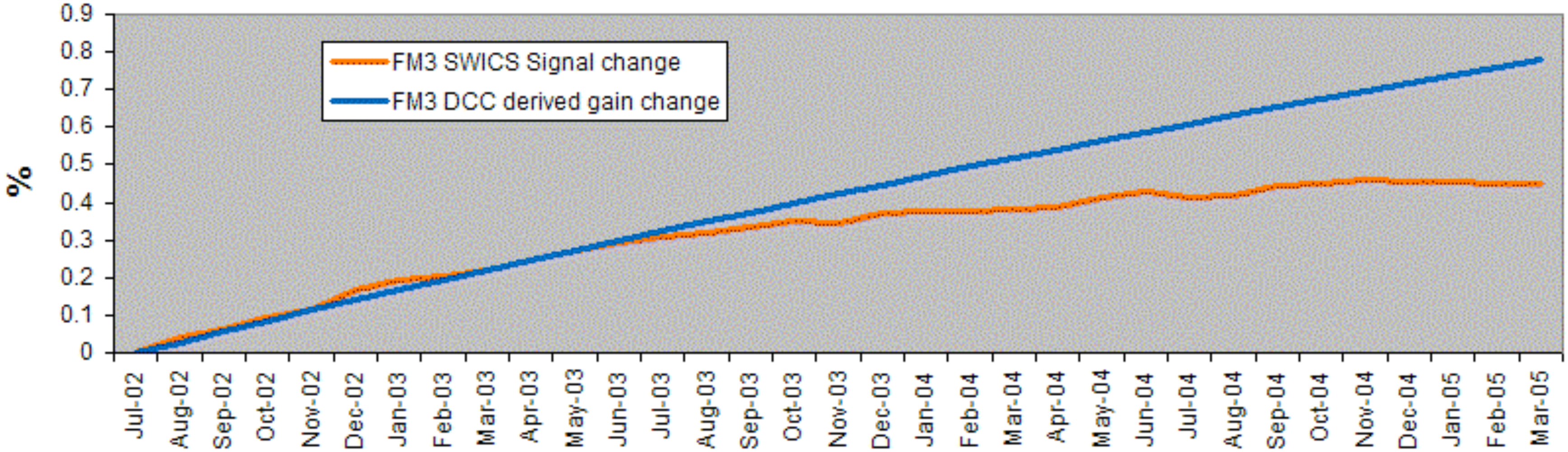
Model fit to Clear Ocean filtered SW Terra direct compare
100*(FM2-FM1)/FM1
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Ed1-CV clear ocean direct compare
Model clear ocean direct compare
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05

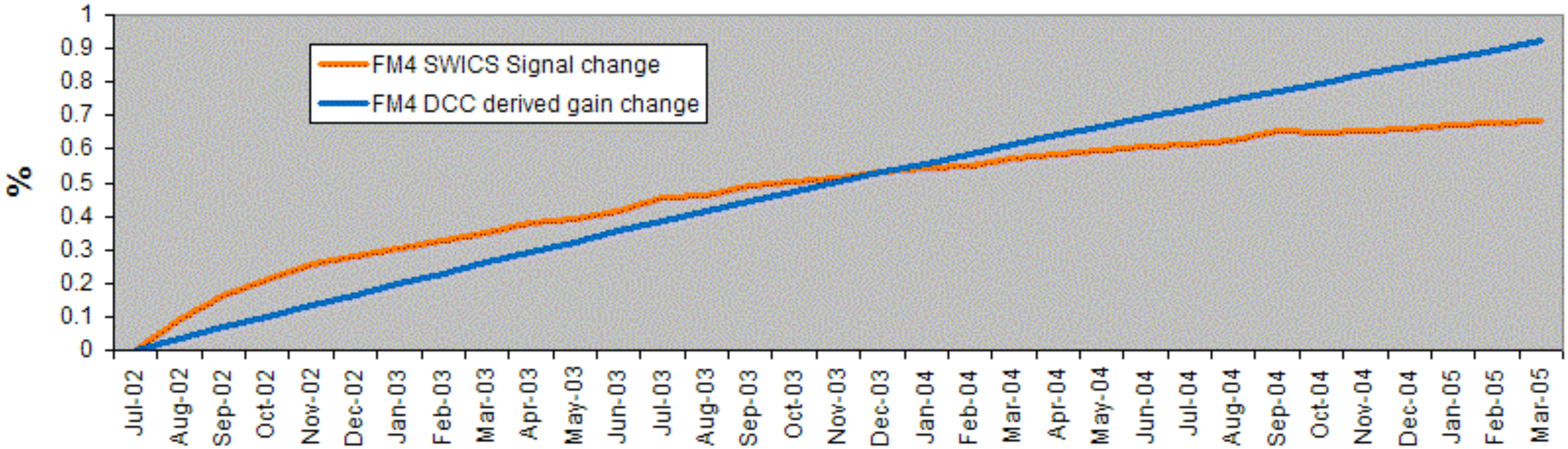
# Terra Deep Convective Cloud SW % Gain change from Mission start



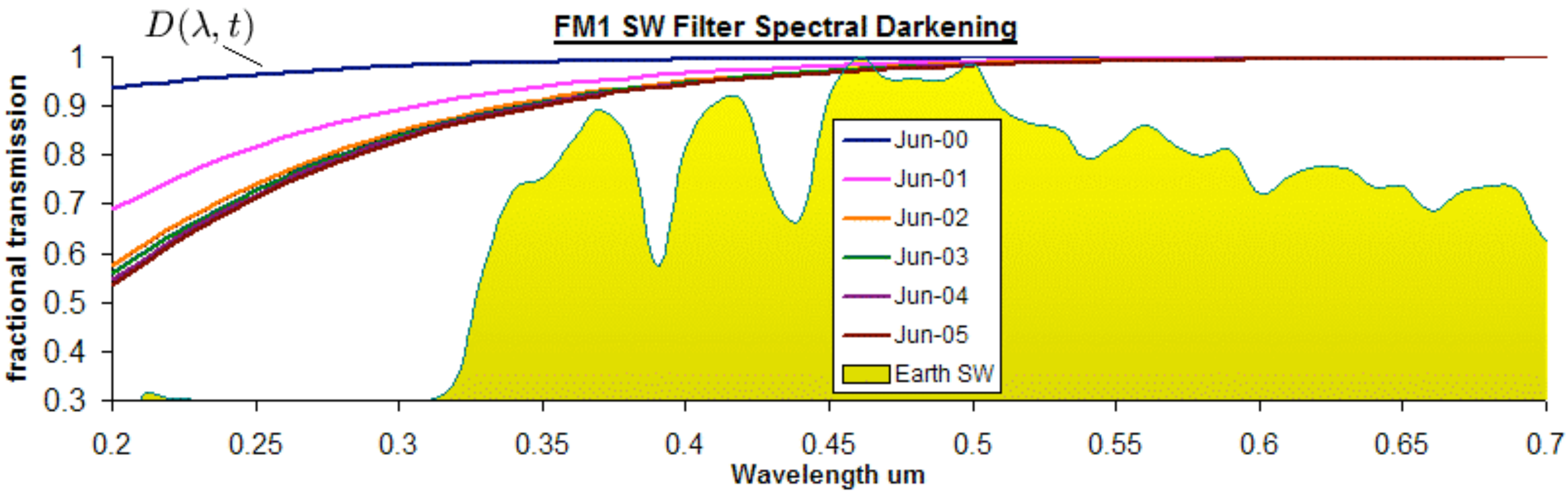



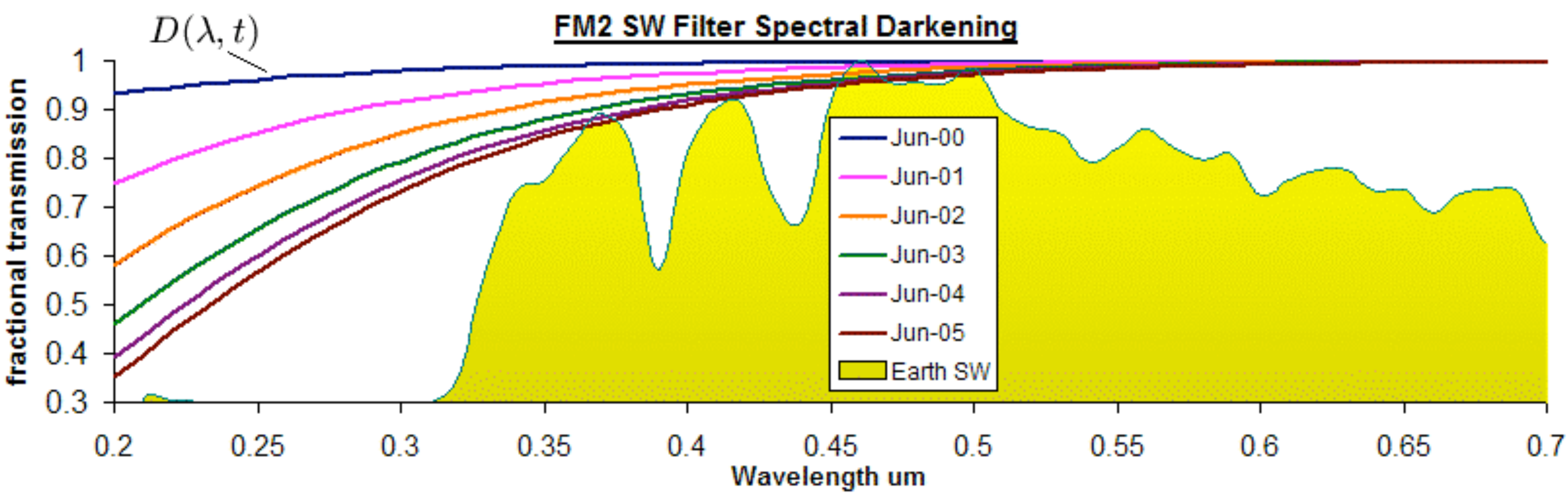
# Aqua Deep Convective Cloud SW % Gain change from Mission start



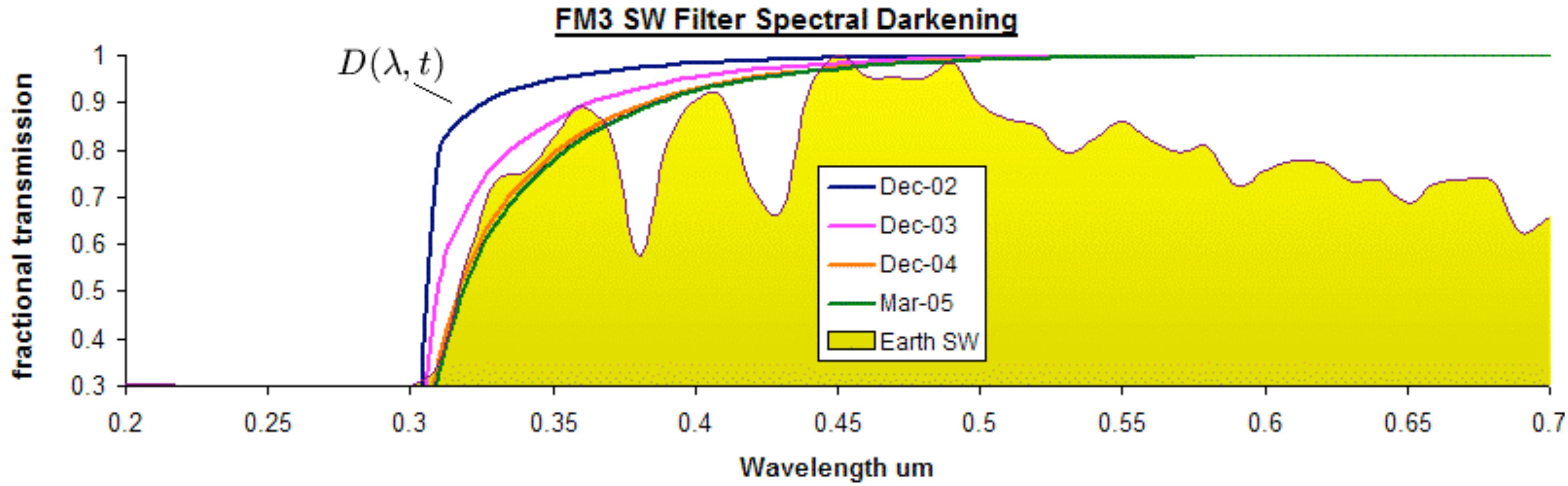



# TERRA

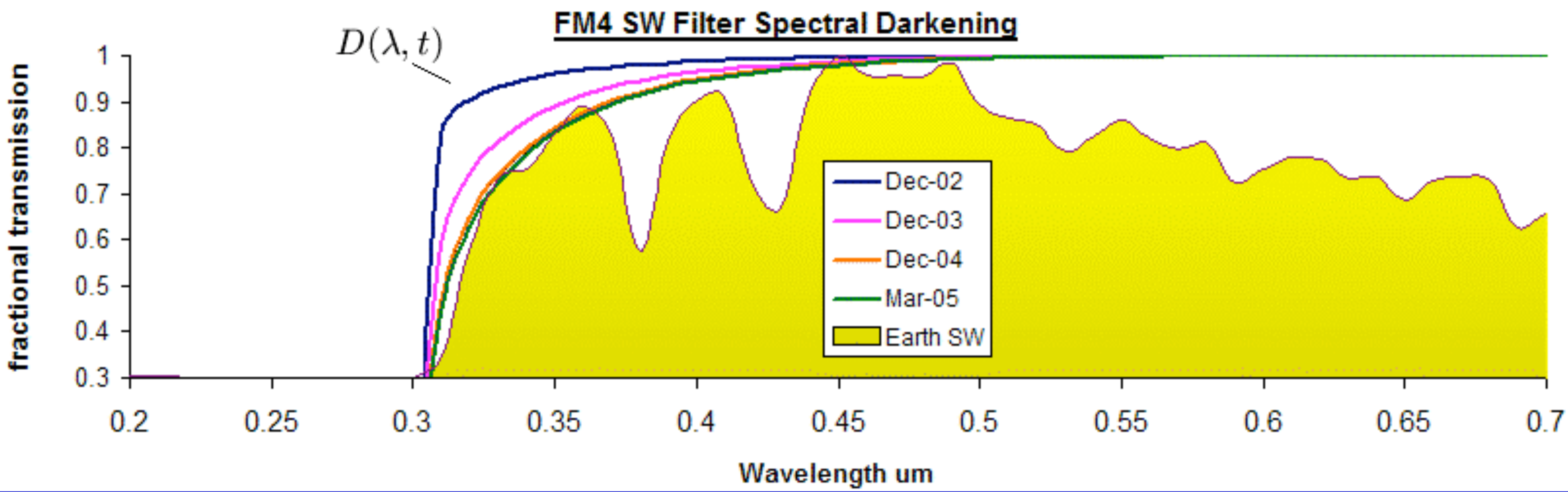

FM1 SW Filter Spectral Darkening
$D(\lambda, t)$
fractional transmission
Wavelength um
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Earth SW


FM2 SW Filter Spectral Darkening
$D(\lambda, t)$
fractional transmission
Wavelength um
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Earth SW

# AQUA

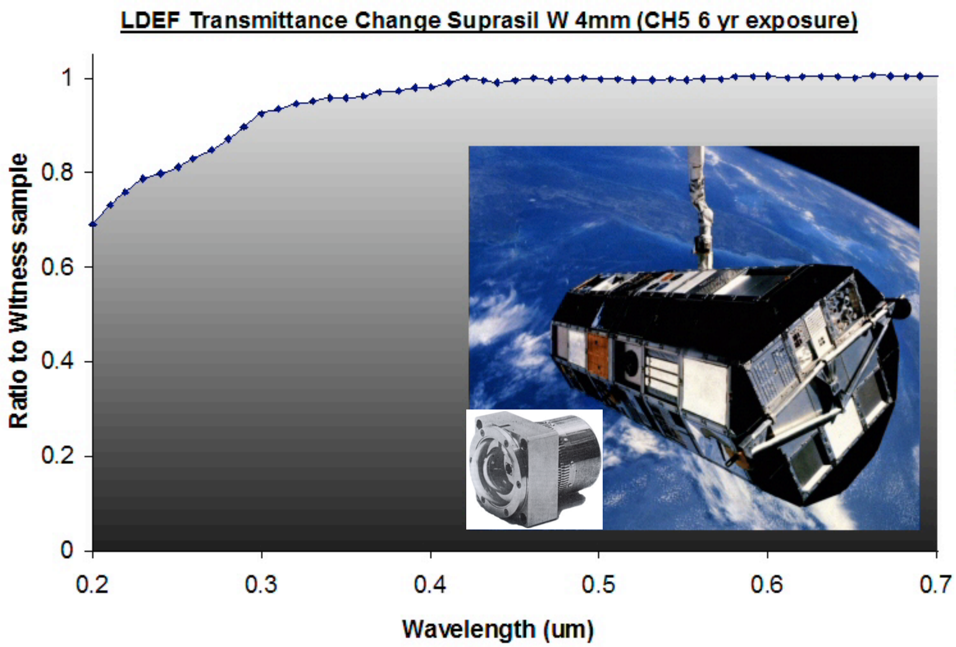


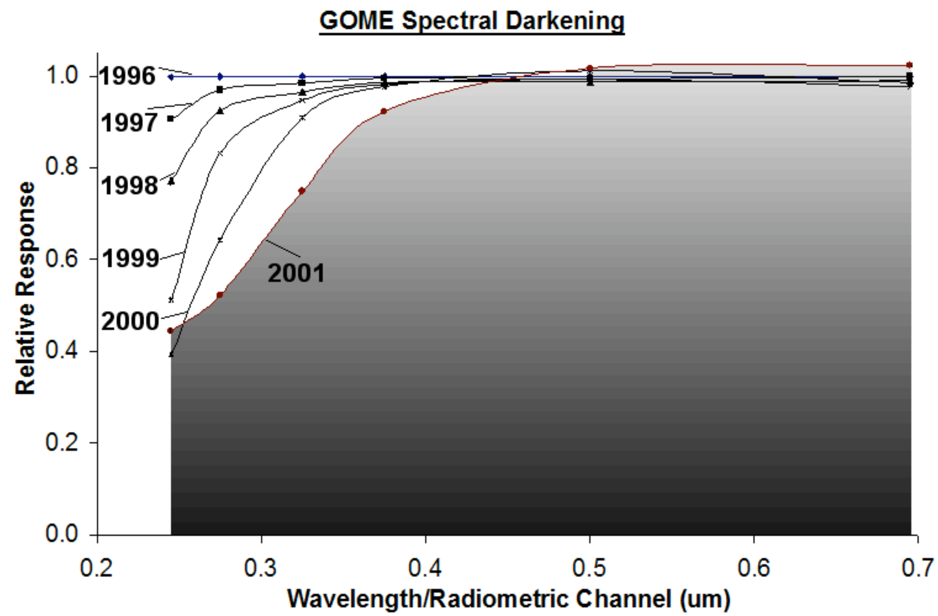
FM3 SW Filter Spectral Darkening
$D(\lambda, t)$
fractional transmission
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
Wavelength um
Dec-02
Dec-03
Dec-04
Mar-05
Earth SW

FM4 SW Filter Spectral Darkening
$D(\lambda, t)$
fractional transmission
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
Wavelength um
Dec-02
Dec-03
Dec-04
Mar-05
Earth SW

# This matches the shape of spectral darkening occurring on LDEF and GOME:

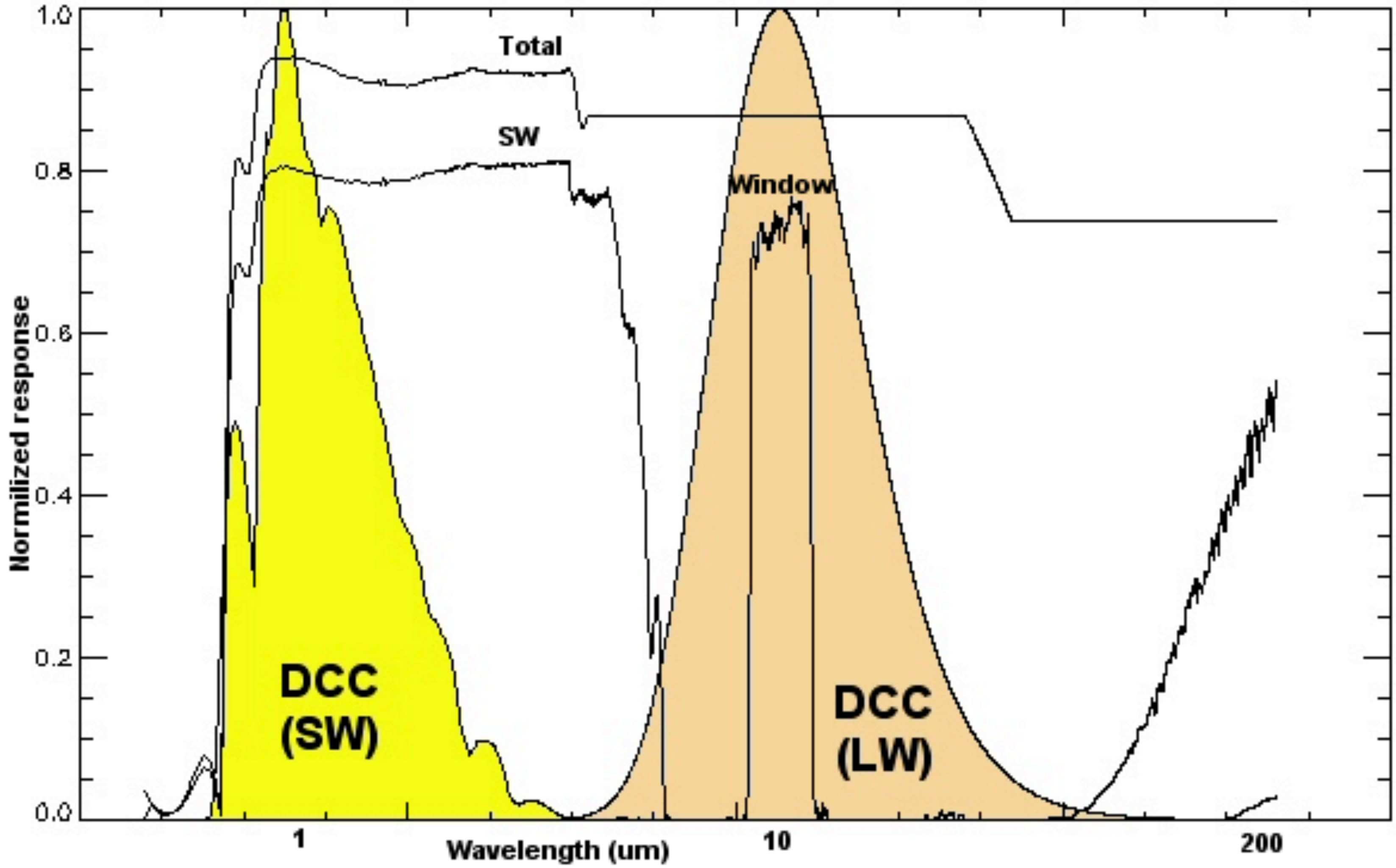


# Total and WN Edition 3 calibration

# ICM Derived Gains and Spectral response based on SW spectral darkening

# SW channel and SW portion of Total must balance exactly to give accurate daytime LW measurement:



## Use BB data to find gains then apply SW darkening to Total channel:

**Black-Body Gain Calculator**

Total and WN gains based on internal cals

$g_{tot}^1(t),\ g_{tot}^2(t),$
$g_{wn}^1(t),\ g_{wn}^2(t)$

**Contaminant Thickness Calculator**

OUTPUTS

Optimal Total + WN Gain and Spectral Responses

$$\left( \begin{array}{c} g_{tot}^1(t),\ g_{tot}^2(t),\ g_{wn}^1(t), \\ g_{wn}^2(t), S_{tot}(\lambda,t)_1,\ S_{tot}(\lambda,t)_2 \end{array} \right)_{\text{Ed3}}$$

INPUTS

Detector outputs from regular on-board calibrations

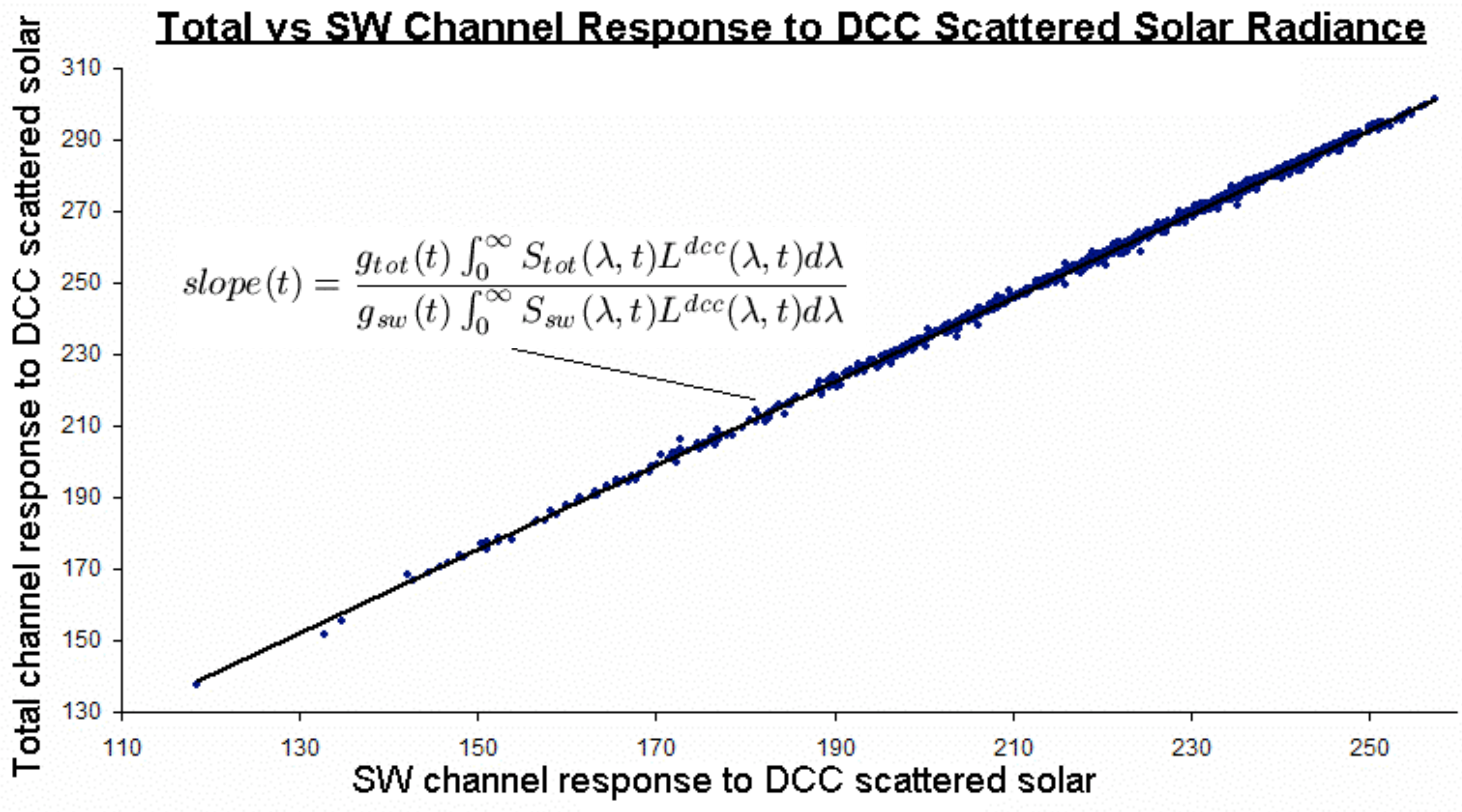
$V_{BB}^{wn}(t)_1,\ V_{BB}^{wn}(t)_2,$
$V_{BB}^{tot}(t)_1,\ V_{BB}^{tot}(t)_2$

INPUTS

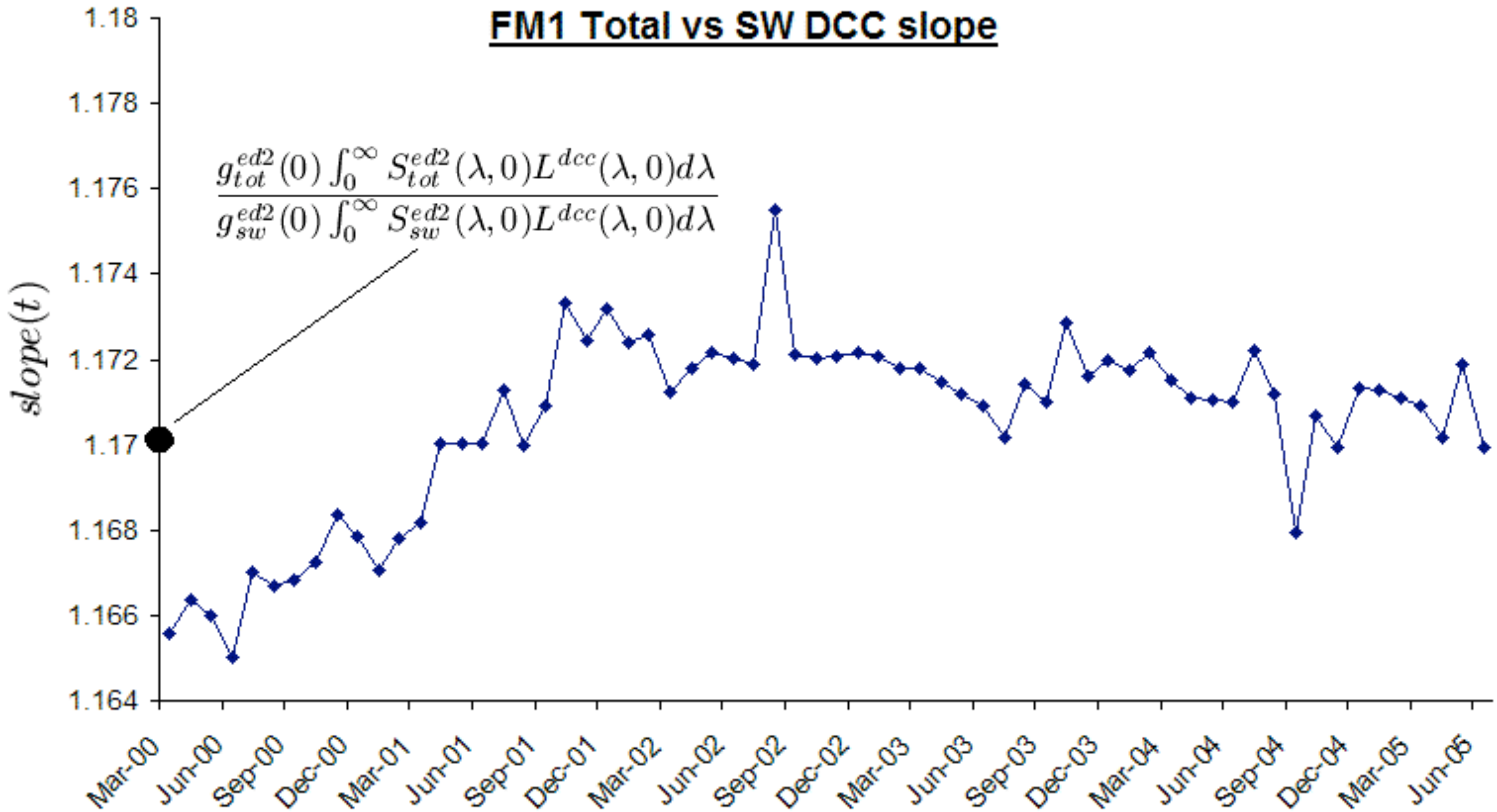
SW gains and spectral responses + simultaneous detector outputs for DCC, Allsky and Clear Ocean

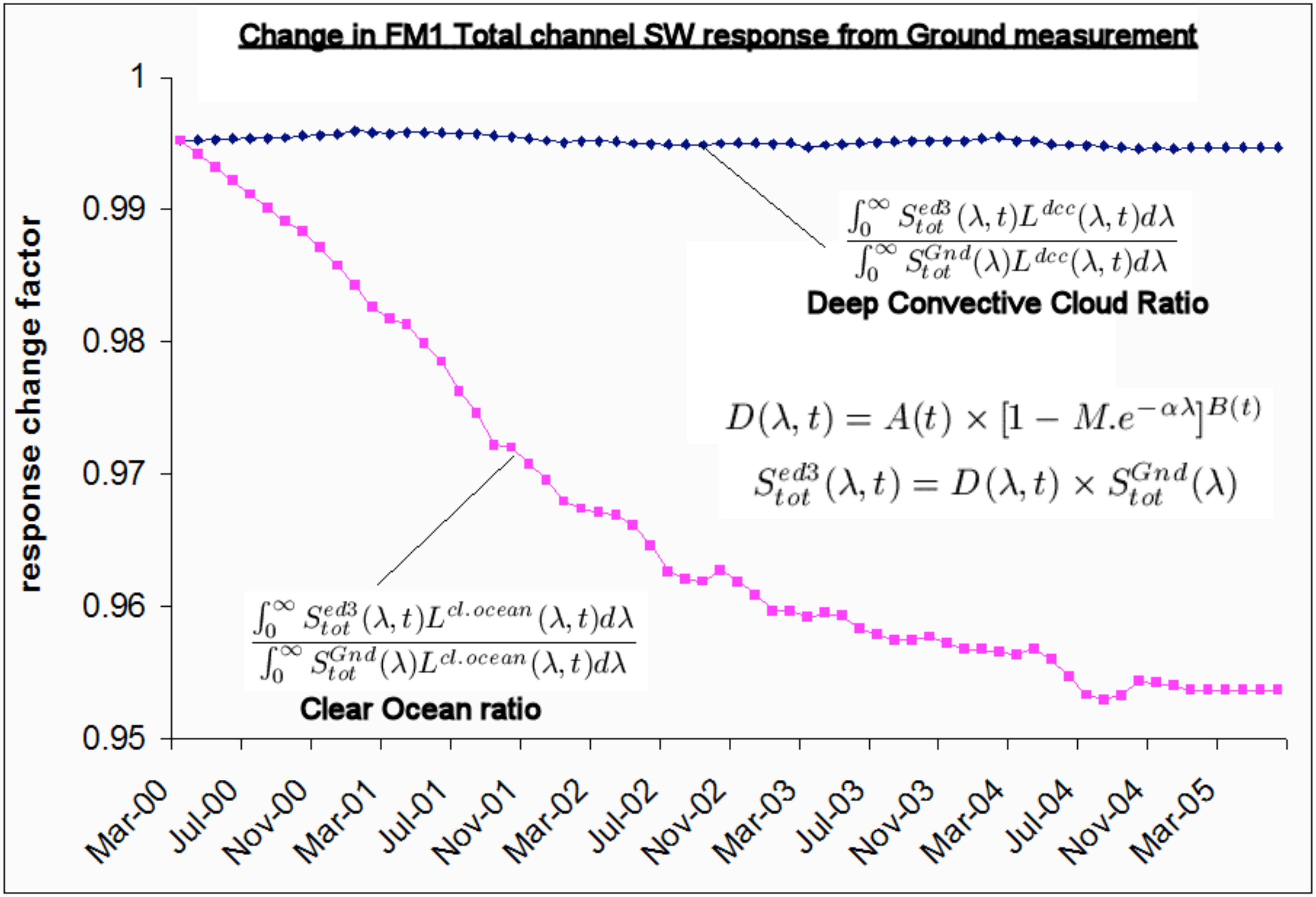
$S_{sw}(\lambda,t)_1,\ S_{sw}(\lambda,t)_2,\ g_{sw}^1(t),\ g_{sw}^2(t),$
$V_i^{sw}(t)_1,\ V_i^{sw}(t)_2, V_i^{tot}(t)_1,\ V_i^{tot}(t)_2,$
$V_i^{wn}(t)_1,\ V_i^{wn}(t)_2$

During day use window channel to remove the filtered LW DCC signal from filtered radiances. Compare Total and SW nadir response to DCC SW radiance:

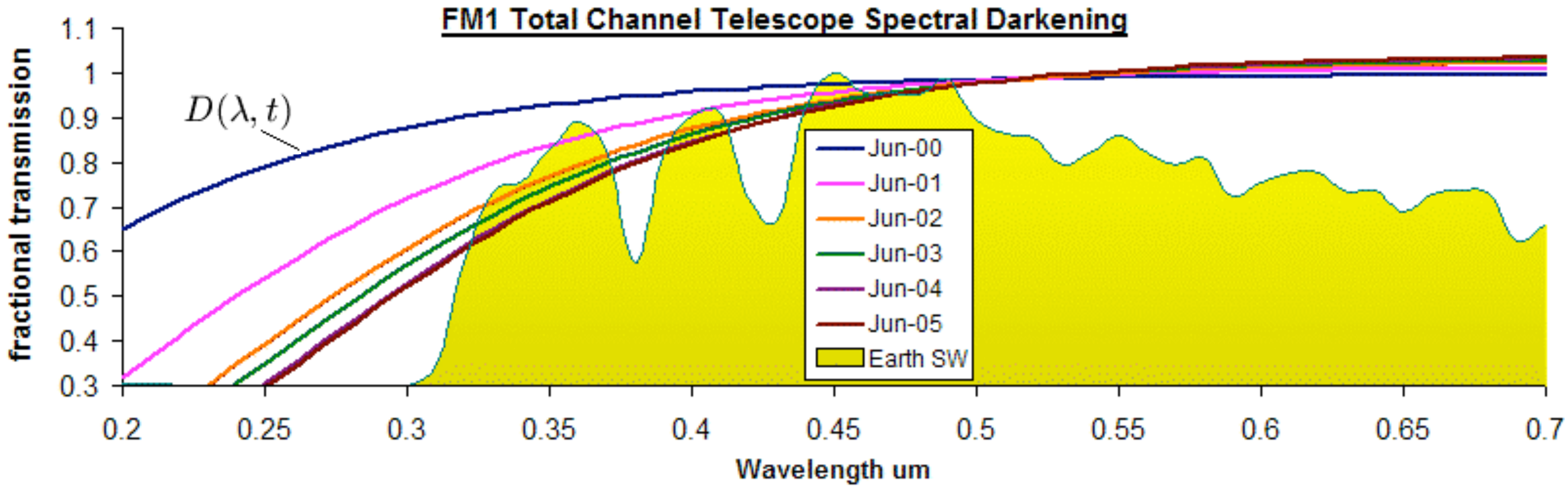


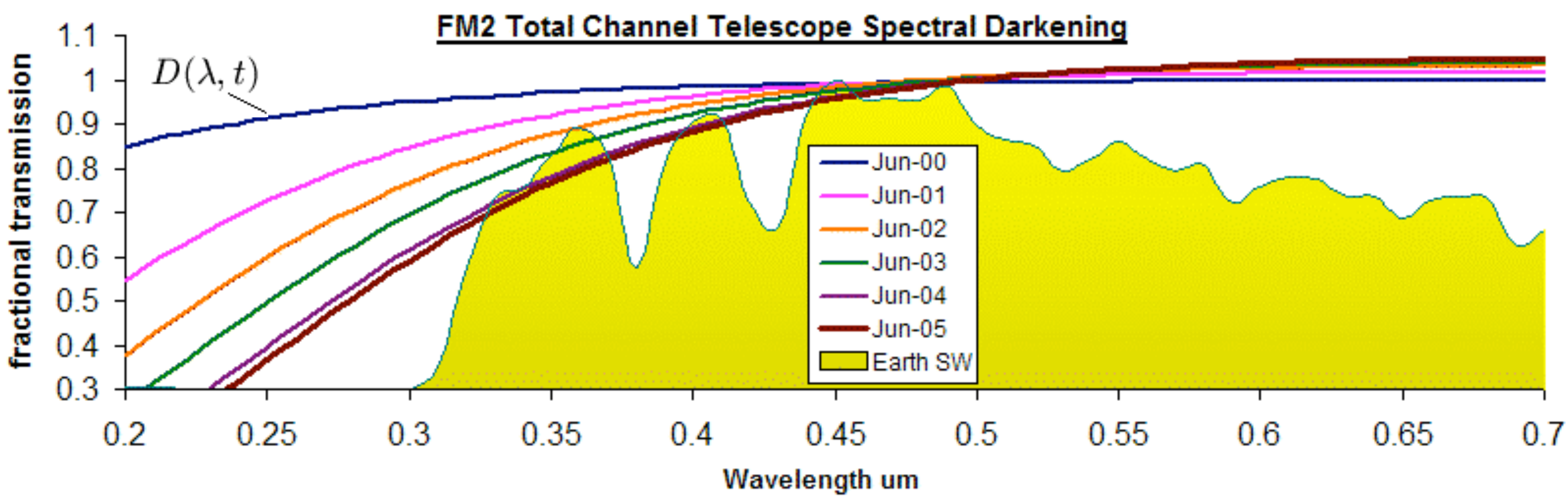
# TERRA

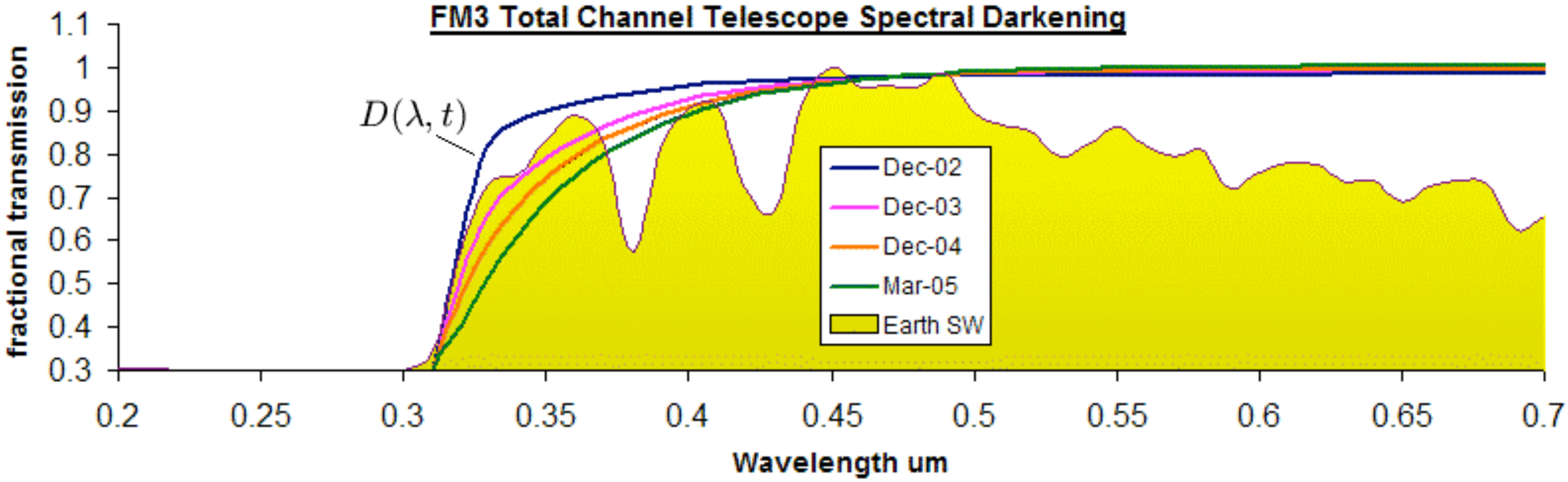

FM1 Total vs SW DCC slope
$$\frac{g_{tot}^{ed2}(0)\int_0^\infty S_{tot}^{ed2}(\lambda,0)L^{dcc}(\lambda,0)d\lambda}{g_{sw}^{ed2}(0)\int_0^\infty S_{sw}^{ed2}(\lambda,0)L^{dcc}(\lambda,0)d\lambda}$$
$slope(t)$
1.18
1.178
1.176
1.174
1.172
1.17
1.168
1.166
1.164
Mar-00
Jun-00
Sep-00
Dec-00
Mar-01
Jun-01
Sep-01
Dec-01
Mar-02
Jun-02
Sep-02
Dec-02
Mar-03
Jun-03
Sep-03
Dec-03
Mar-04
Jun-04
Sep-04
Dec-04
Mar-05
Jun-05

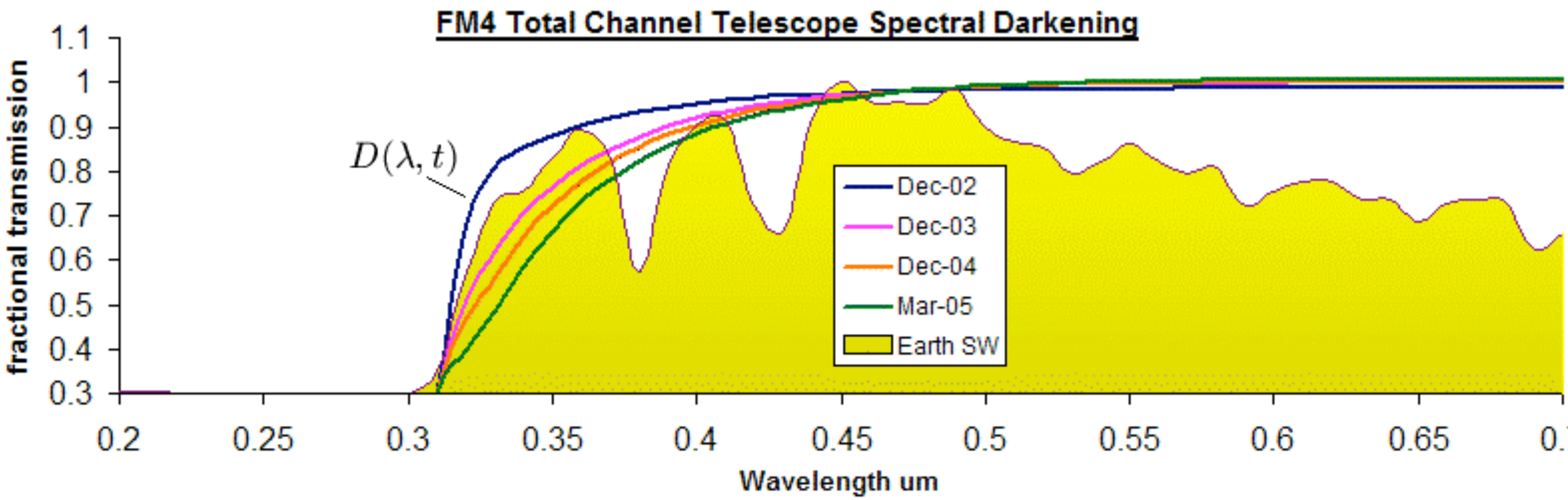


Change in FM1 Total channel SW response from Ground measurement
response change factor
1
0.99
0.98
0.97
0.96
0.95
Mar-00
Jul-00
Nov-00
Mar-01
Jul-01
Nov-01
Mar-02
Jul-02
Nov-02
Mar-03
Jul-03
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
$\frac{\int_0^\infty S_{tot}^{ed3}(\lambda,t)L^{dcc}(\lambda,t)d\lambda}{\int_0^\infty S_{tot}^{Gnd}(\lambda)L^{dcc}(\lambda,t)d\lambda}$
Deep Convective Cloud Ratio
$D(\lambda,t) = A(t) \times [1 - M.e^{-\alpha\lambda}]^{B(t)}$
$S_{tot}^{ed3}(\lambda,t) = D(\lambda,t) \times S_{tot}^{Gnd}(\lambda)$
$\frac{\int_0^\infty S_{tot}^{ed3}(\lambda,t)L^{cl.ocean}(\lambda,t)d\lambda}{\int_0^\infty S_{tot}^{Gnd}(\lambda)L^{cl.ocean}(\lambda,t)d\lambda}$
Clear Ocean ratio


FM1 Total Channel Telescope Spectral Darkening
$D(\lambda, t)$
fractional transmission
Wavelength um
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Earth SW
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7

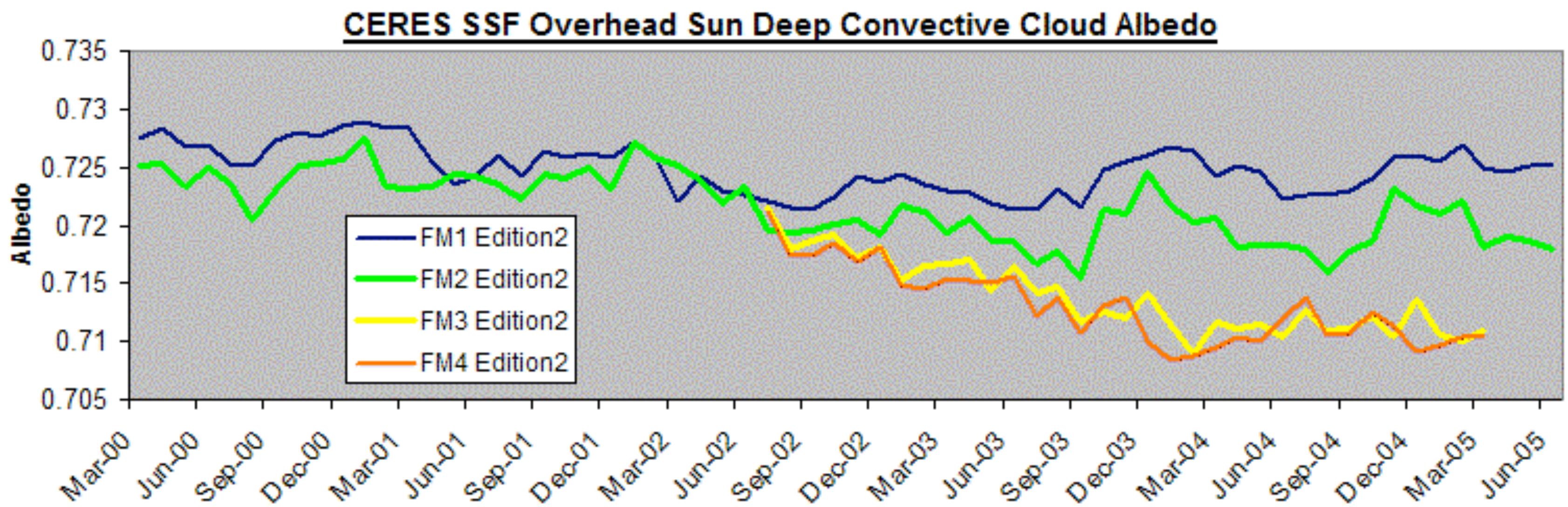

FM2 Total Channel Telescope Spectral Darkening
$D(\lambda, t)$
fractional transmission
Wavelength um
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Earth SW
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7

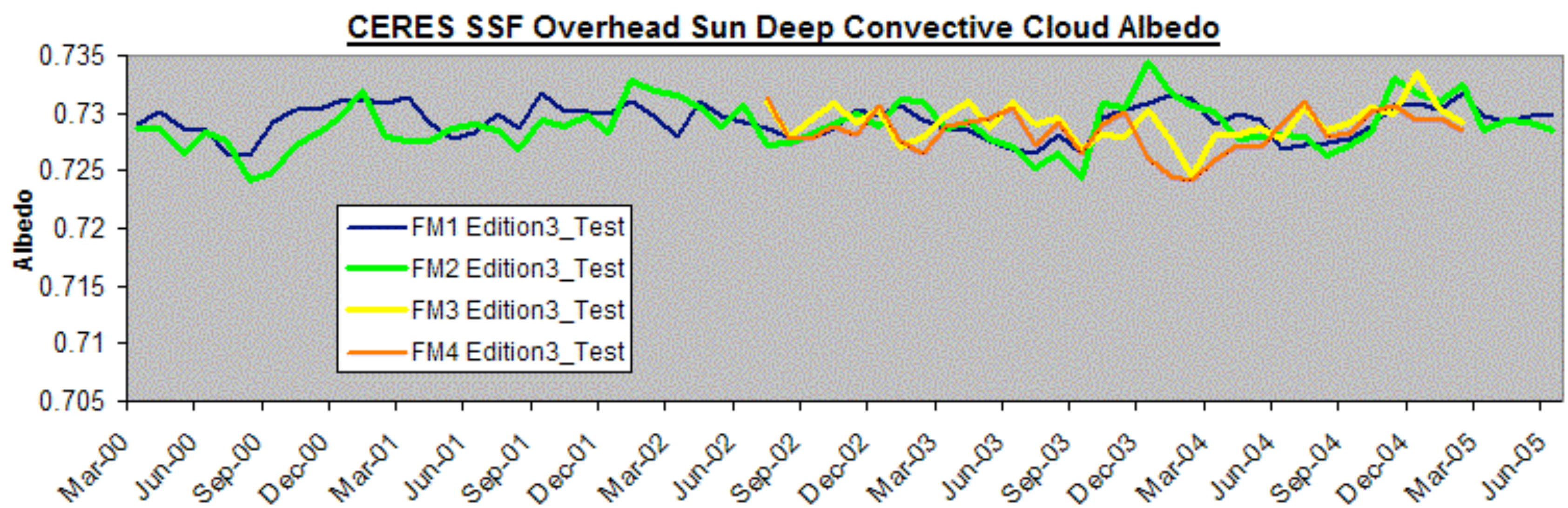

FM3 Total Channel Telescope Spectral Darkening
fractional transmission
Wavelength um
$D(\lambda, t)$
Dec-02
Dec-03
Dec-04
Mar-05
Earth SW
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7


FM4 Total Channel Telescope Spectral Darkening
fractional transmission
Wavelength um
$D(\lambda, t)$
Dec-02
Dec-03
Dec-04
Mar-05
Earth SW
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7

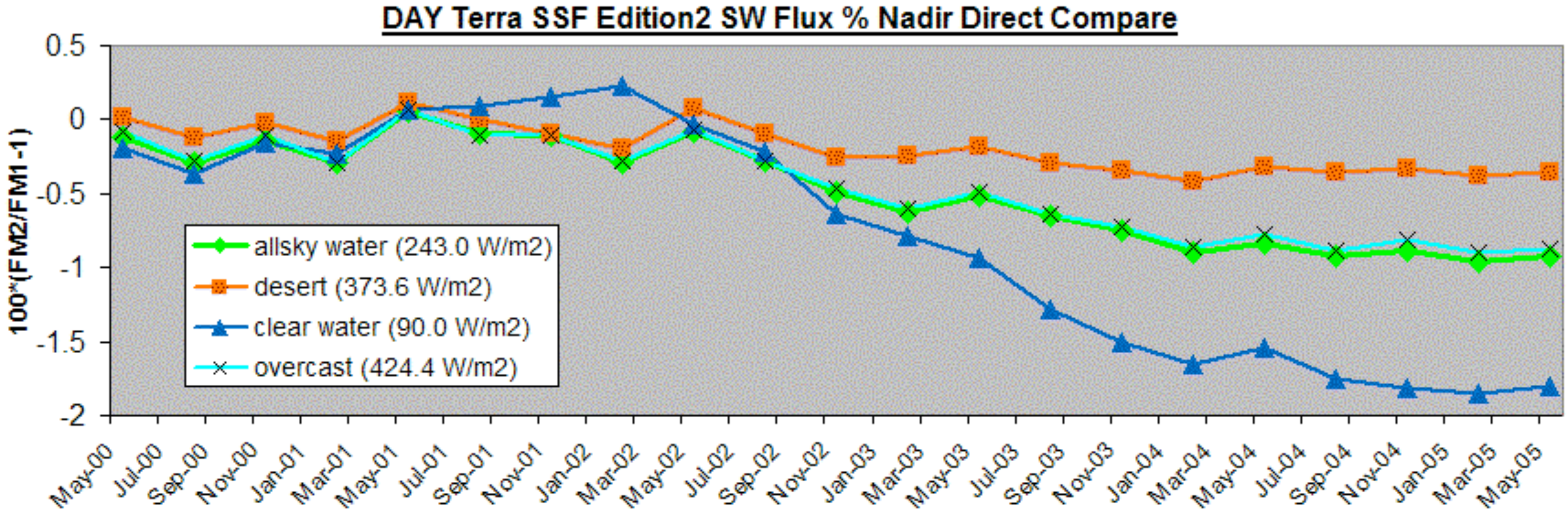
# Edition 3 Test SSF data run Results compared to Edition 2 SSF

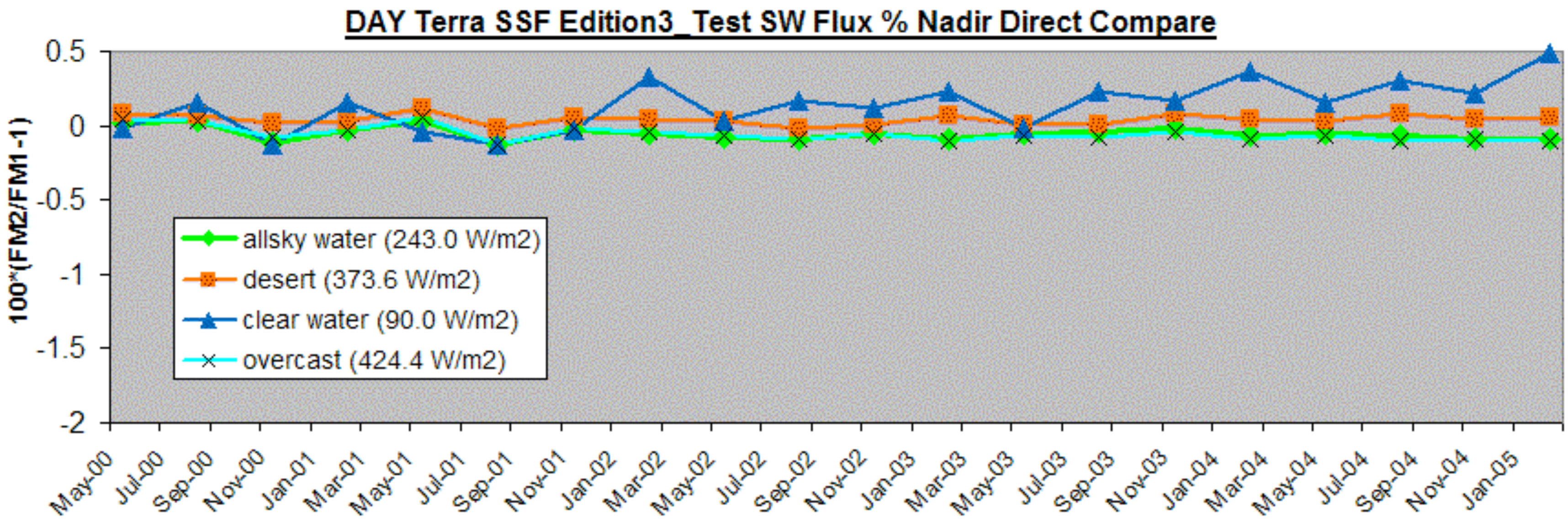
# SSF Edition3 Test run changes from Edition2



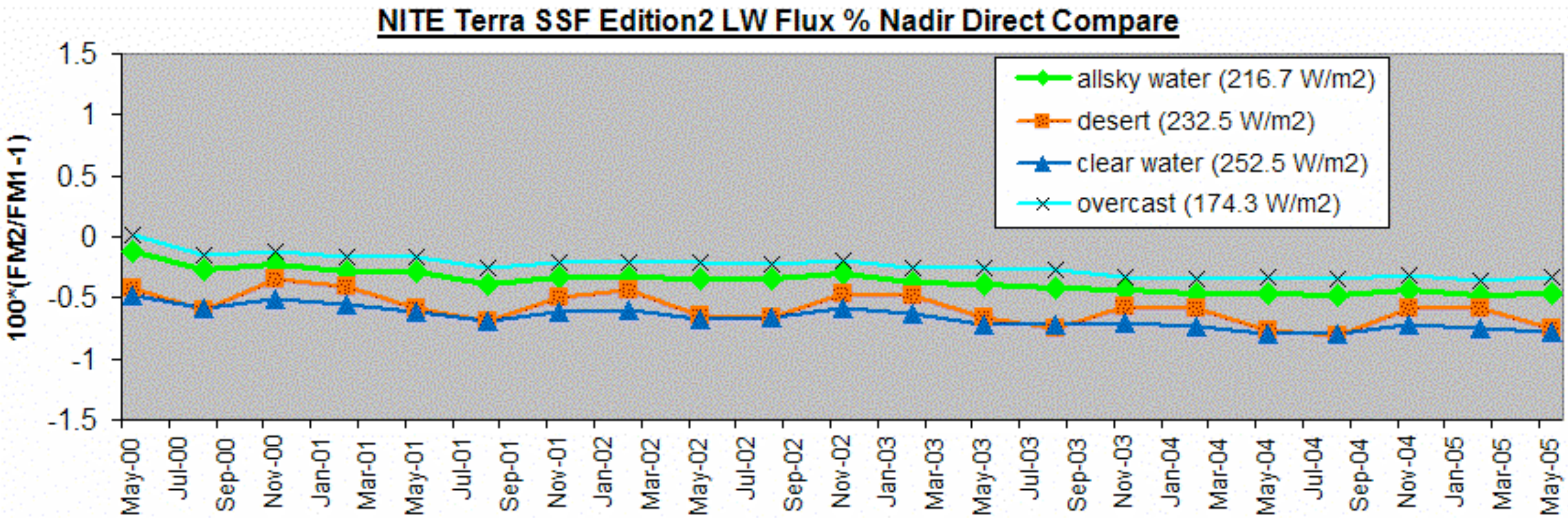



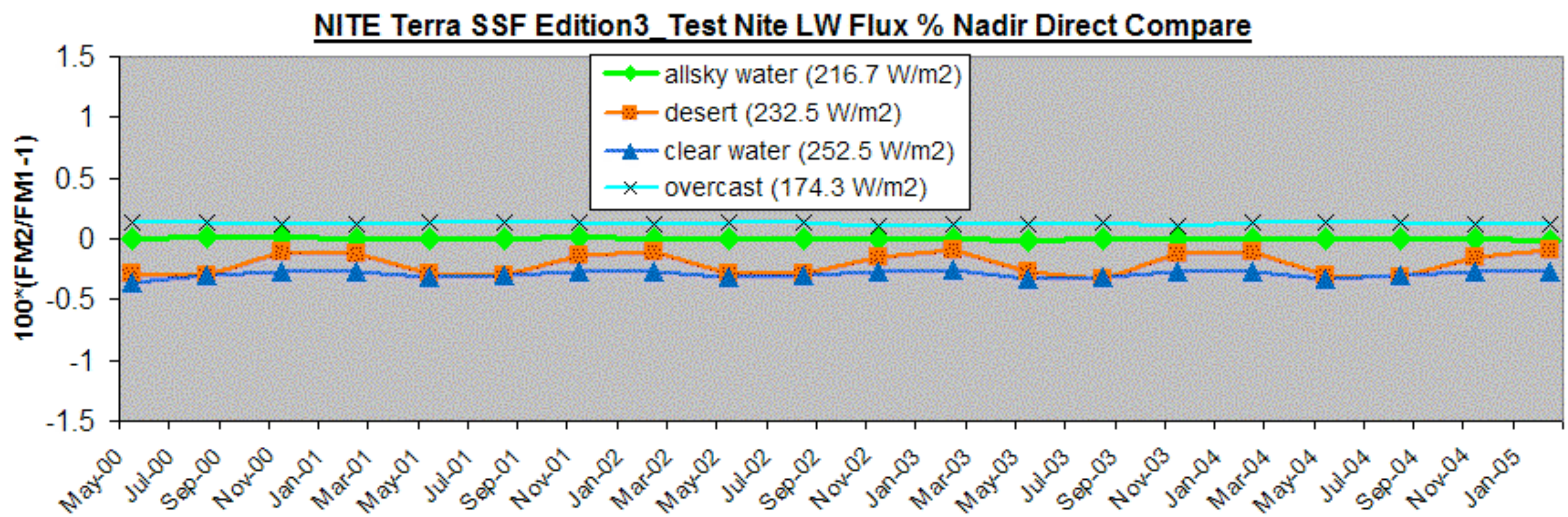
# SSF Edition3 Test run changes from Edition2



# SSF Edition3 Test run changes from Edition2



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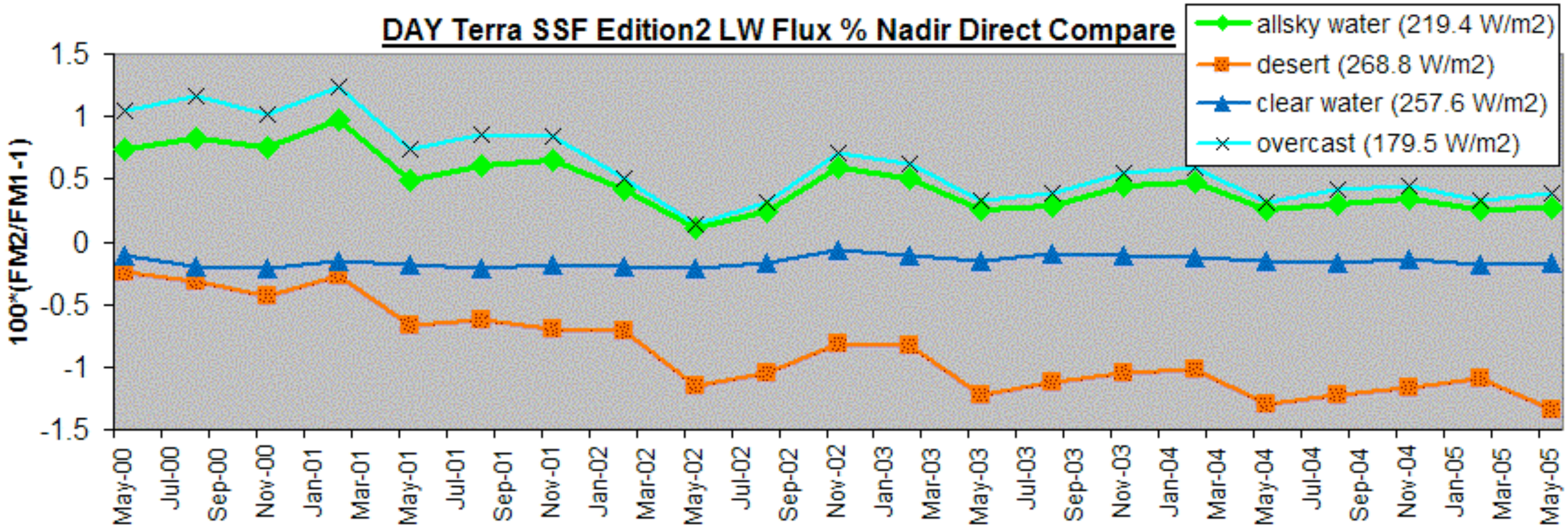
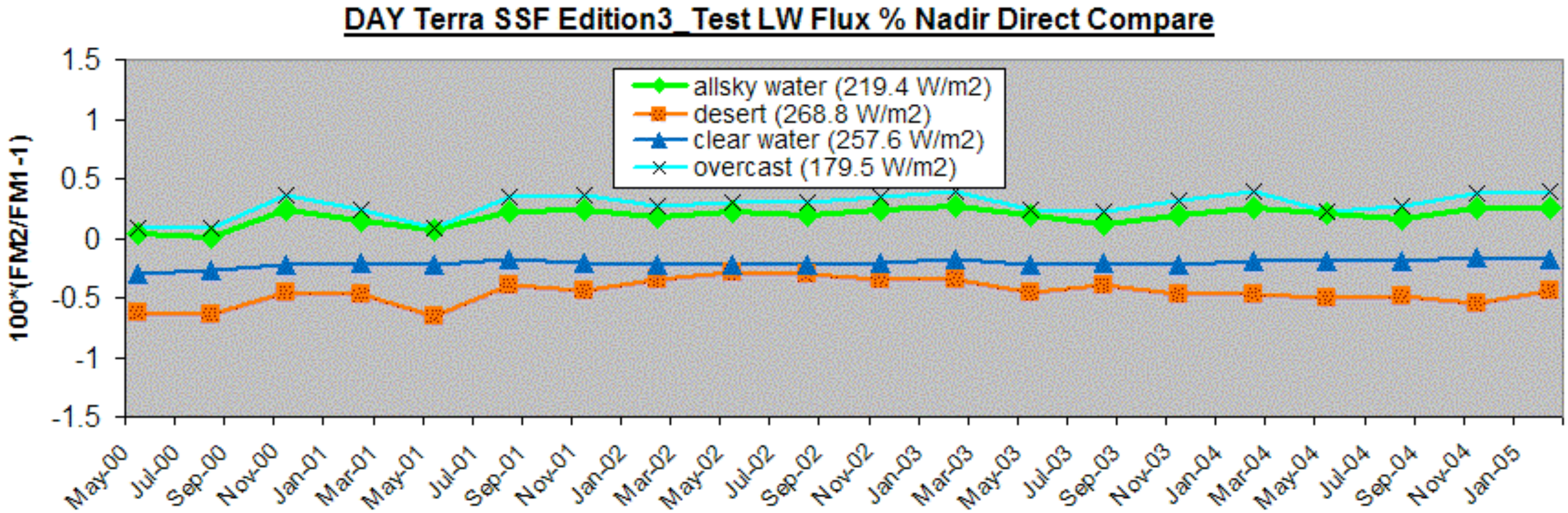
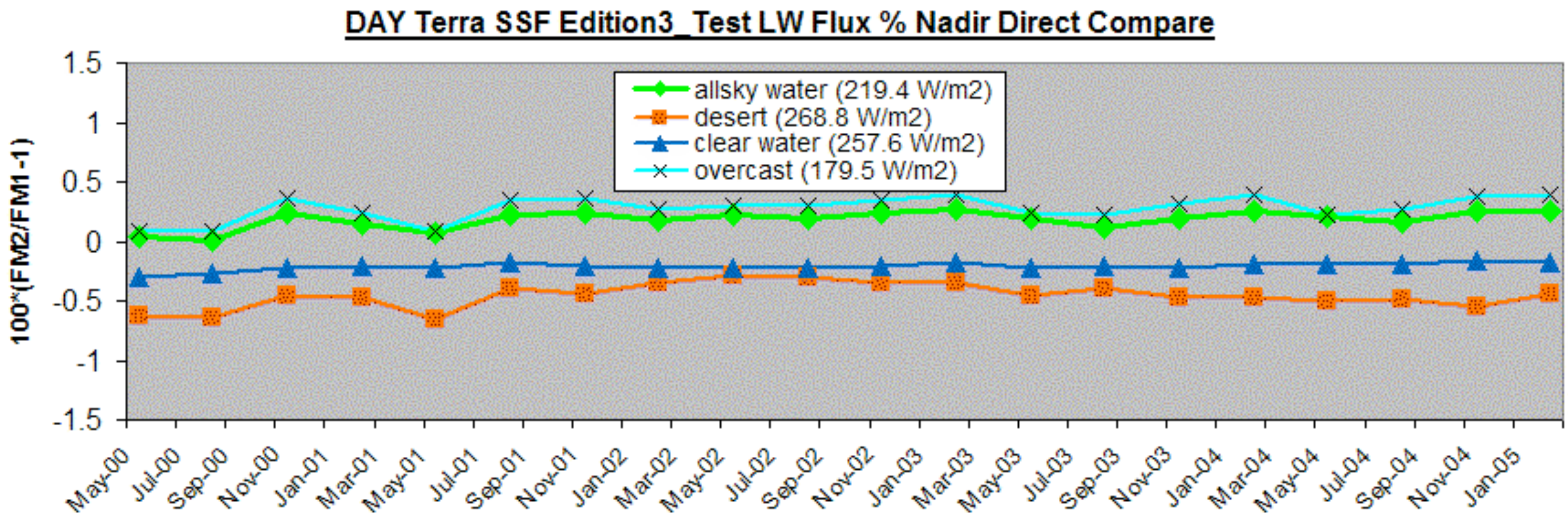
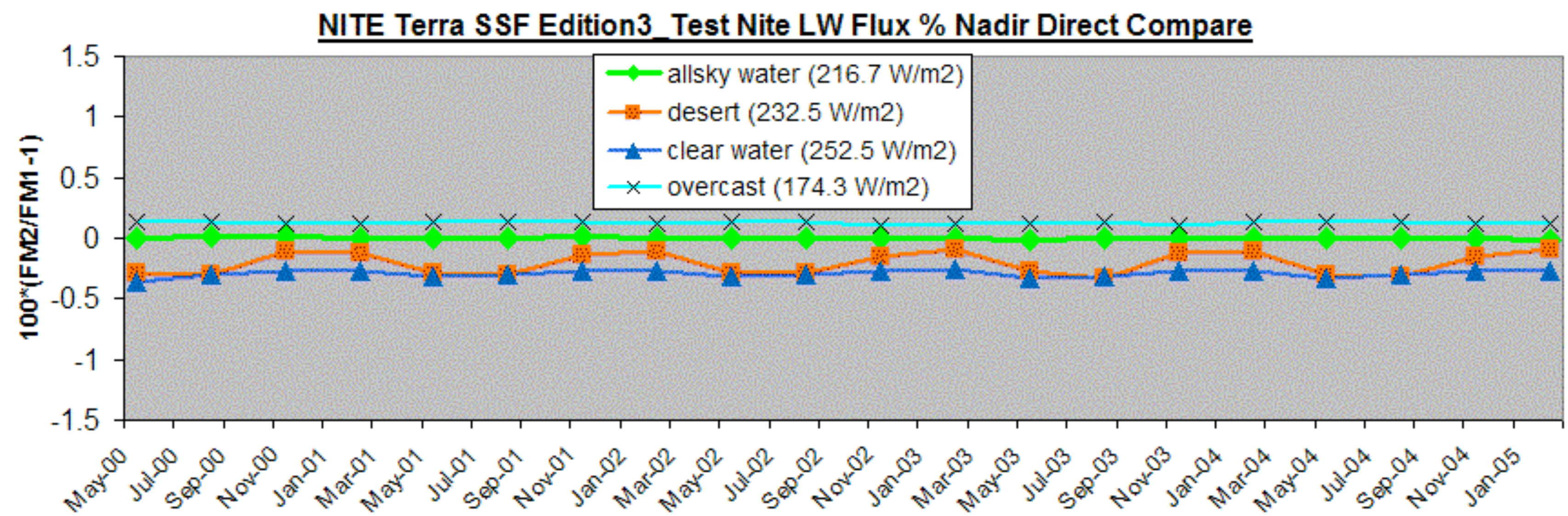


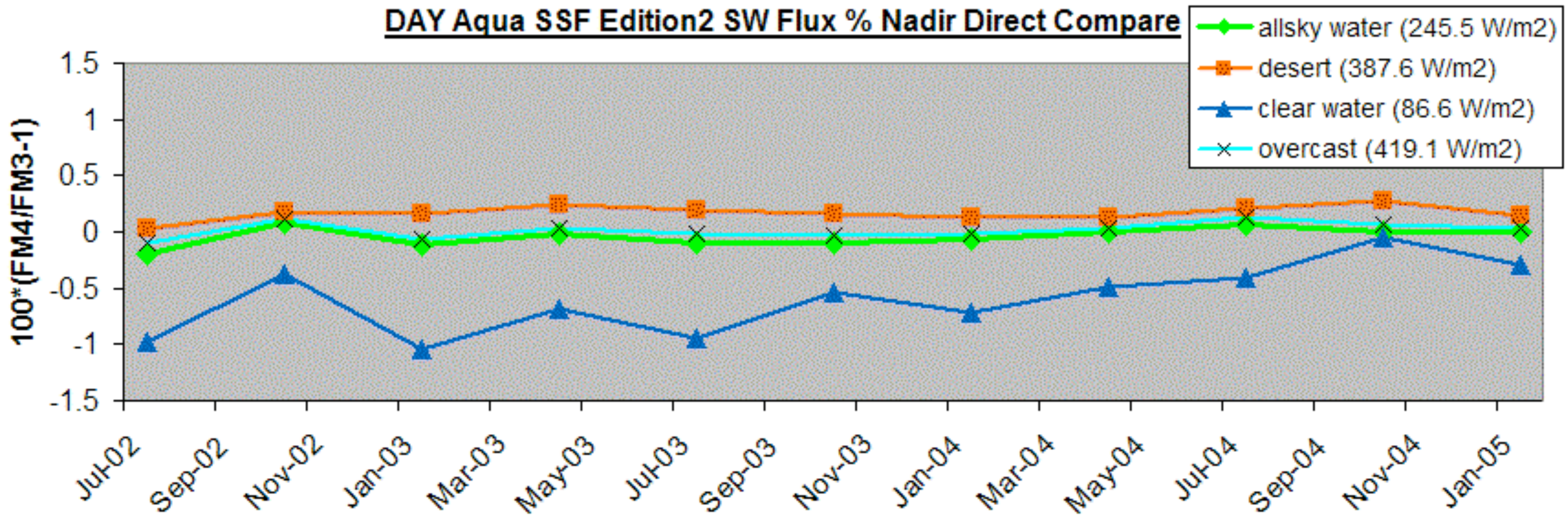



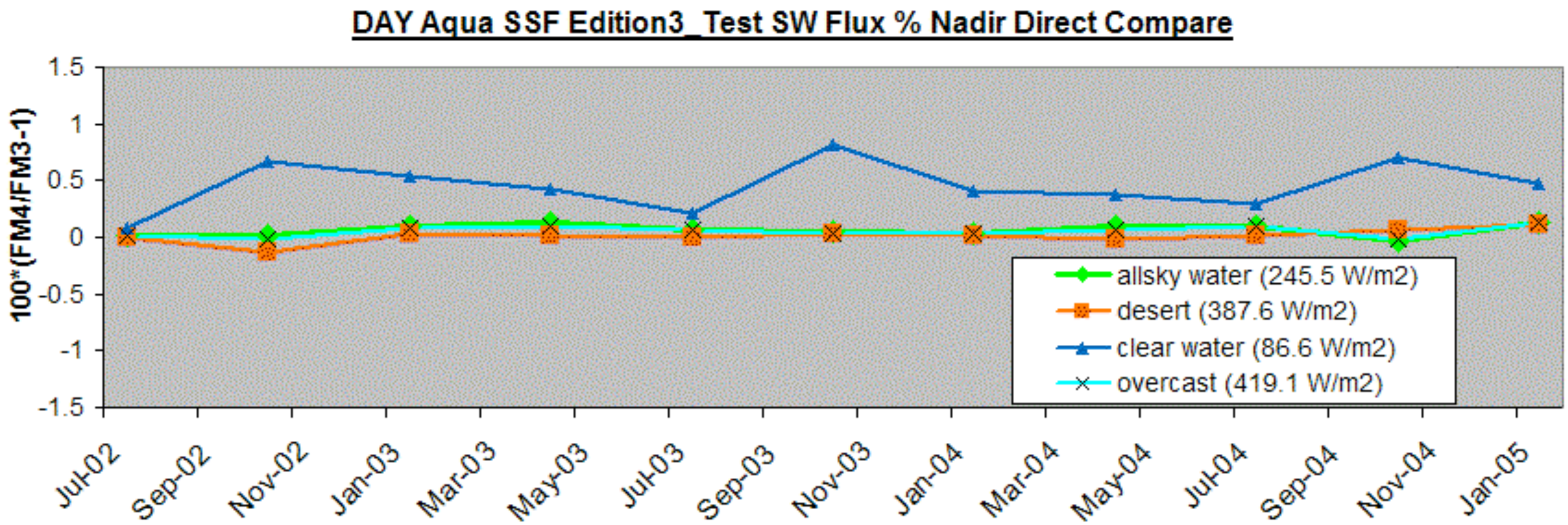
# SSF Edition3 Test run changes



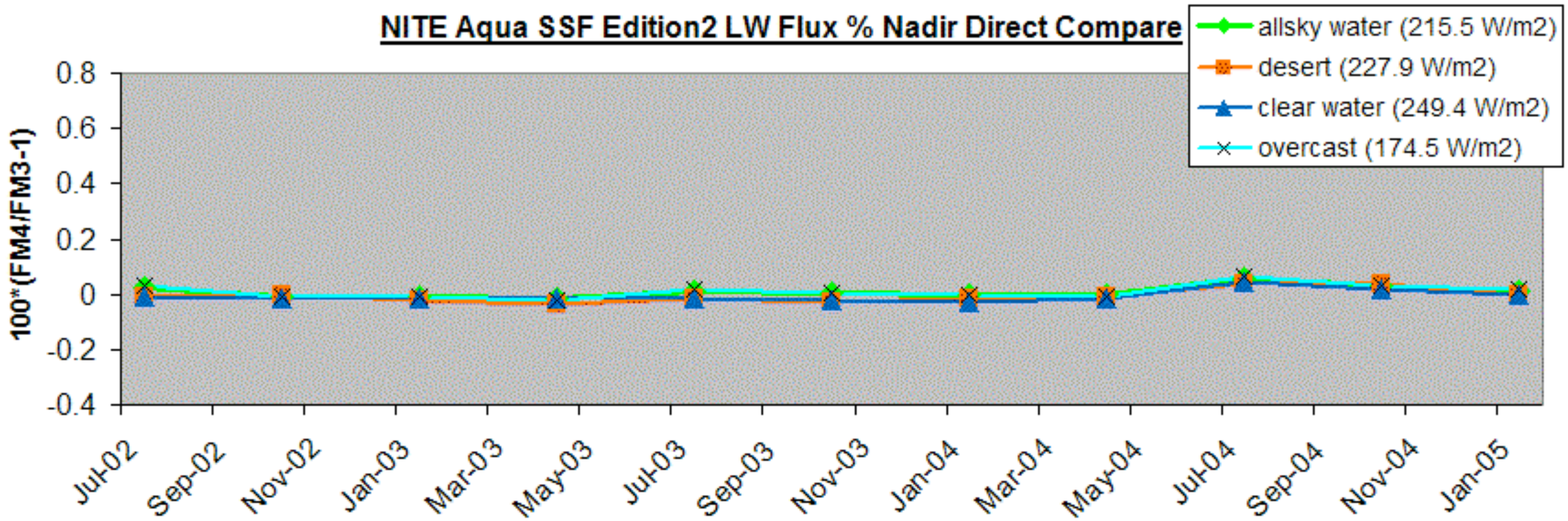



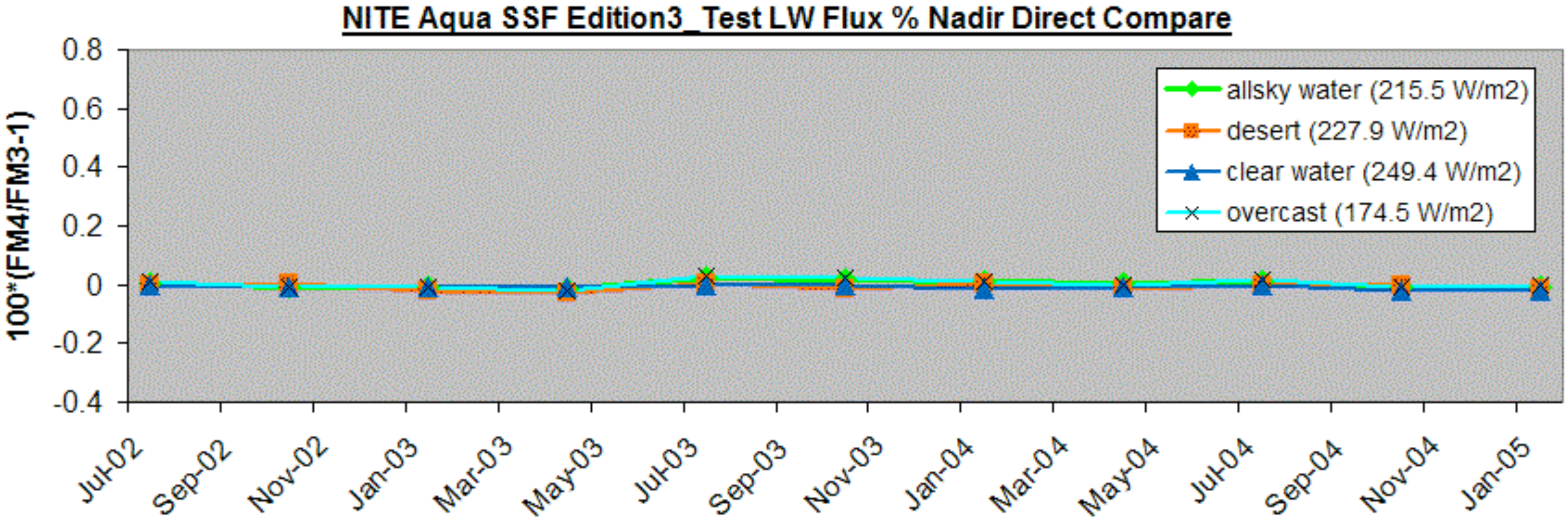
# SSF Edition3 Test run changes from Edition2



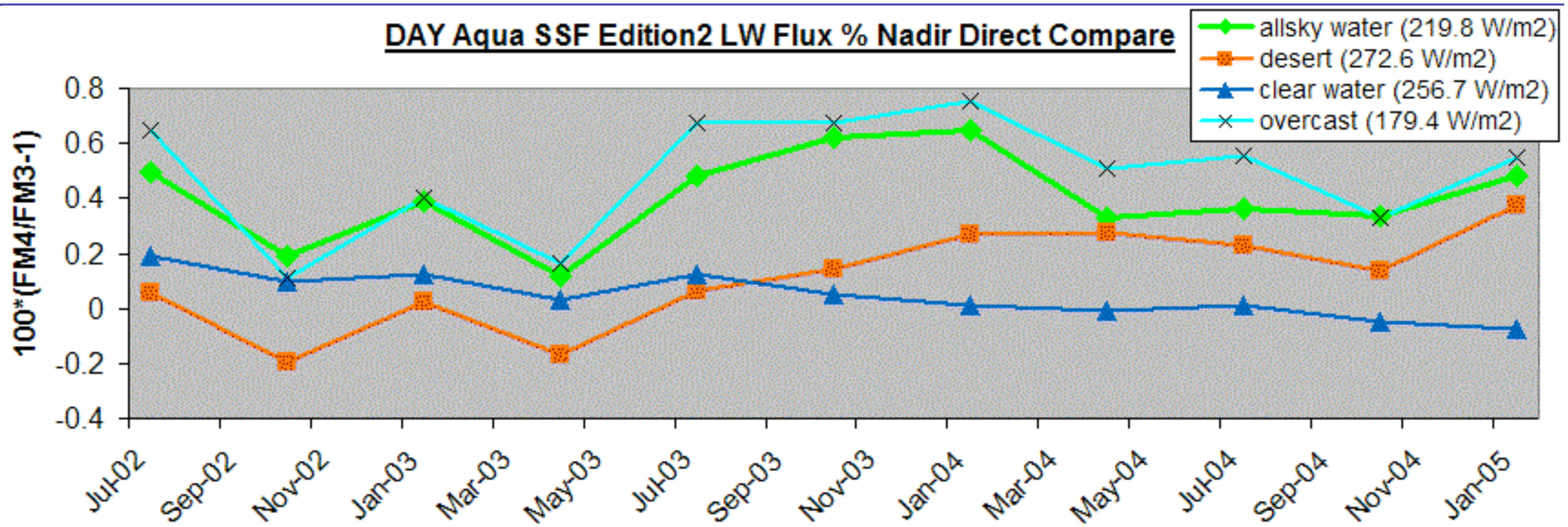



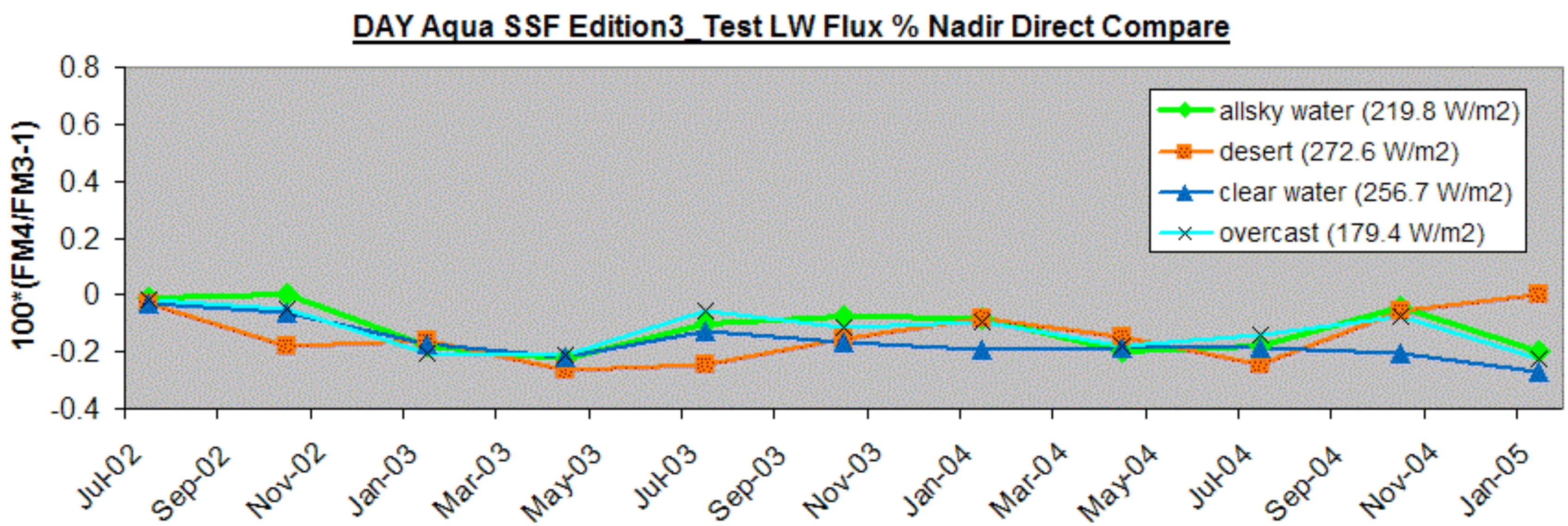
# SSF Edition3 Test run changes from Edition2



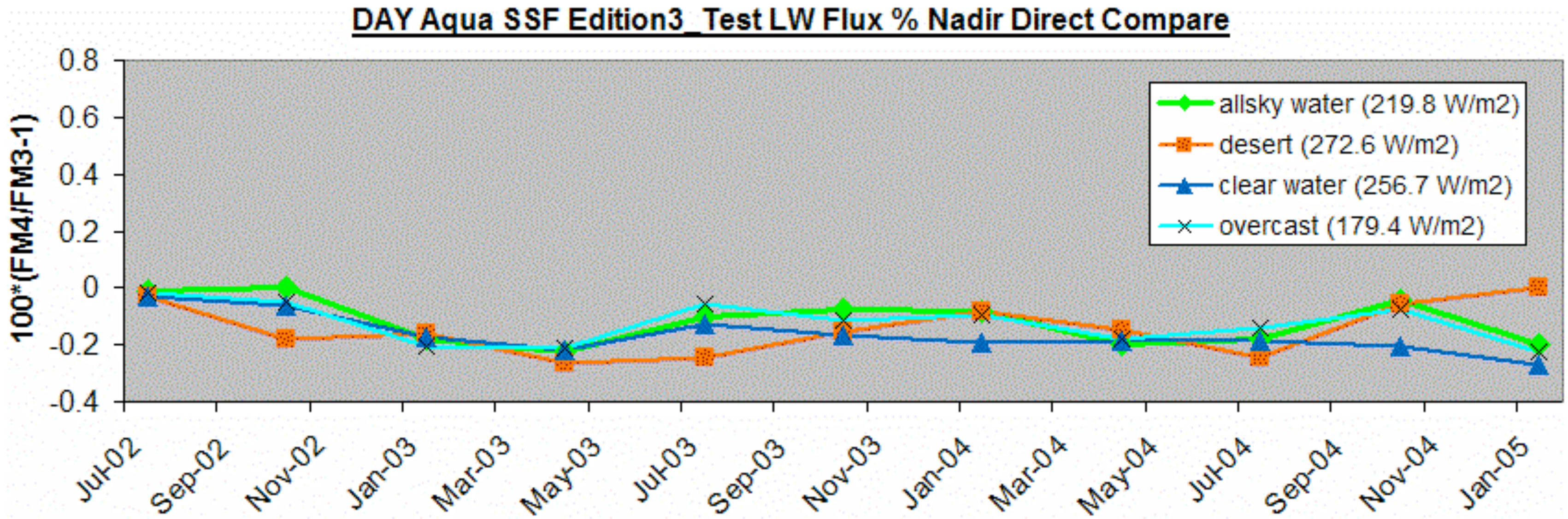



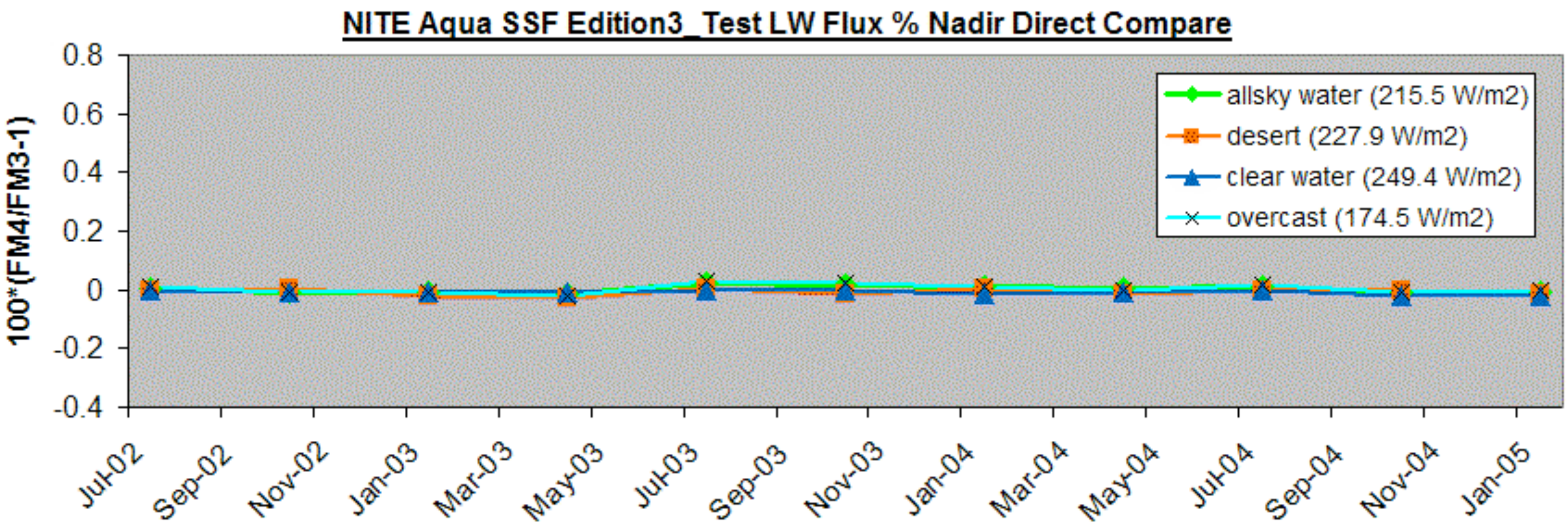
# SSF Edition3 Test run changes from Edition2



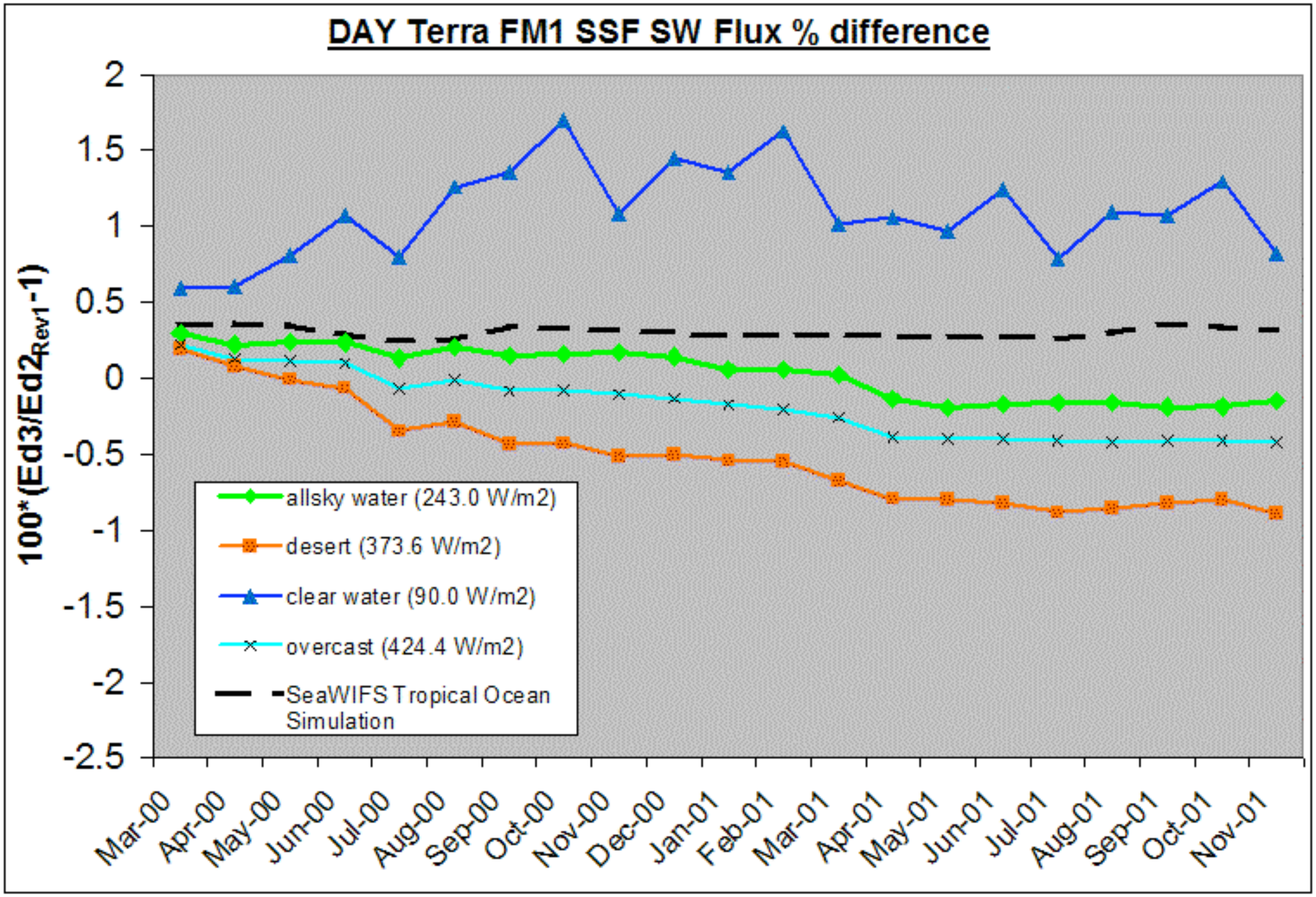



# SSF Edition3 Test run changes



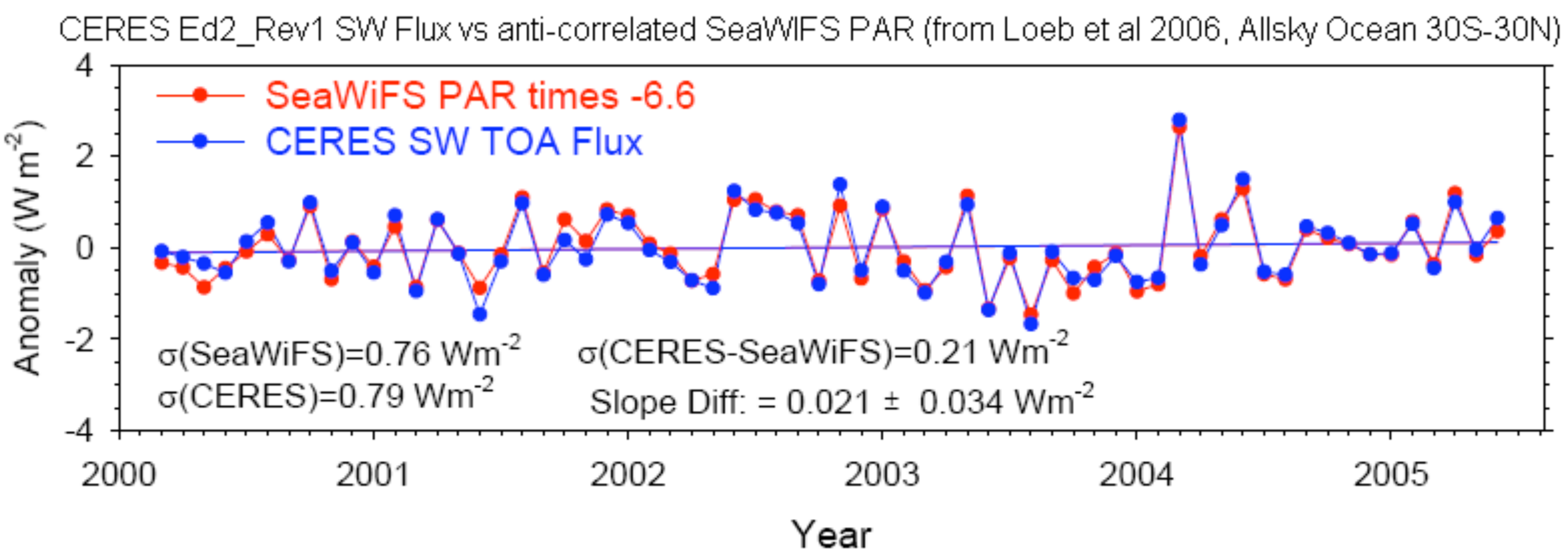



# SSF Edition3 Test run changes from Edition2$_{\mathrm{Rev1}}$

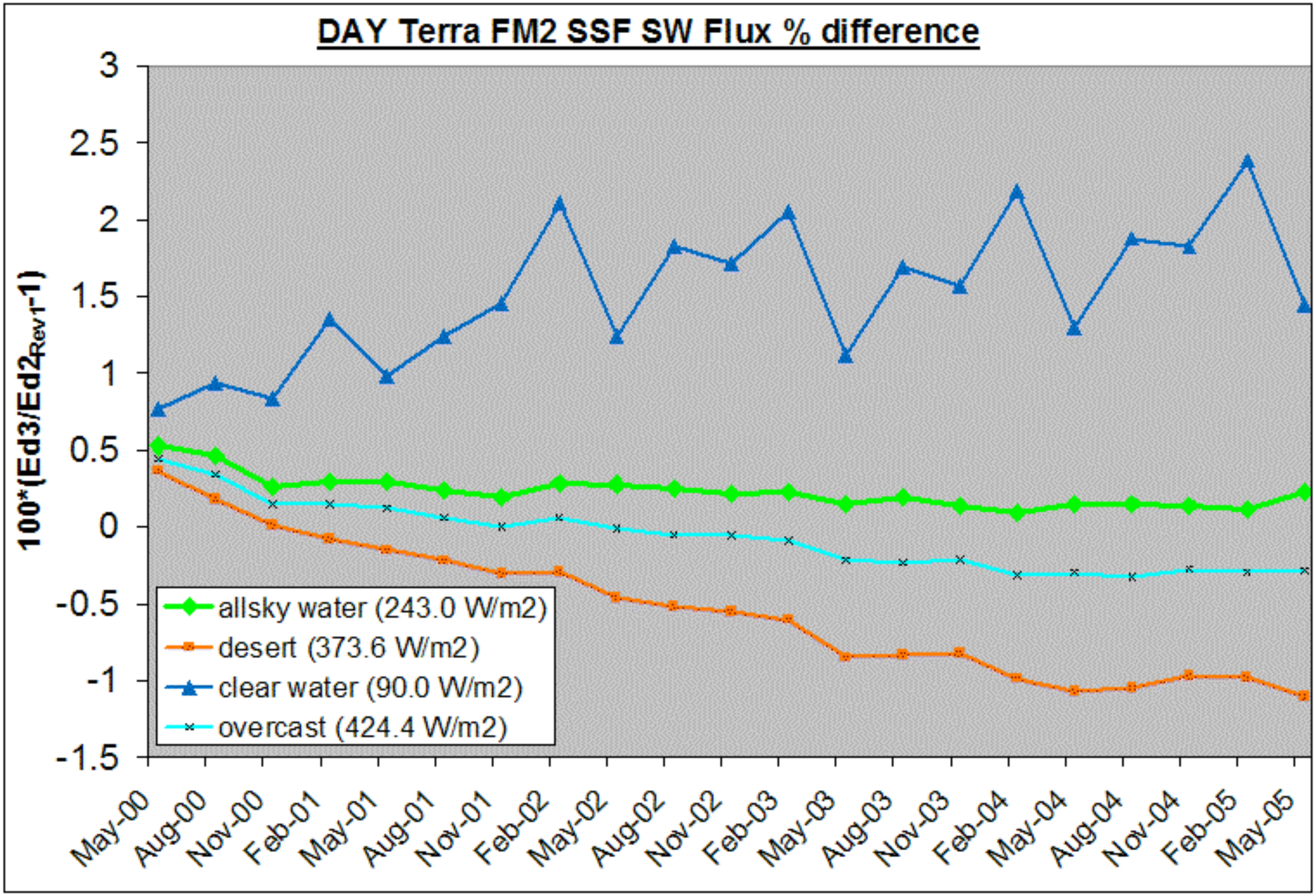


# SSF Edition3 Test run changes from Edition2$_{Rev1}$

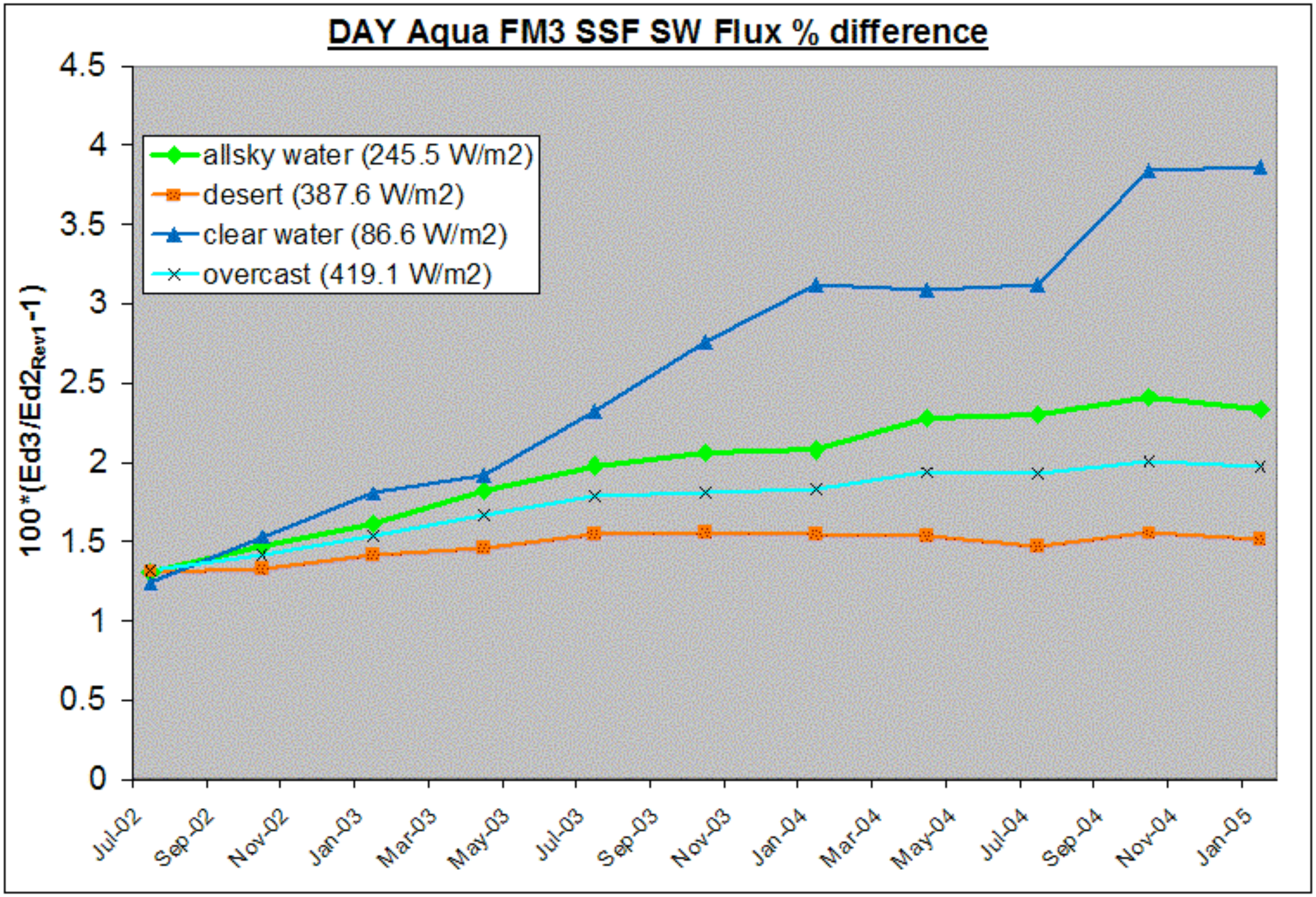
Hence SSF Edition3 Test run data should show the same excellent agreement with anti-correlated SeaWIFS PAR as Edition 2 Rev1:



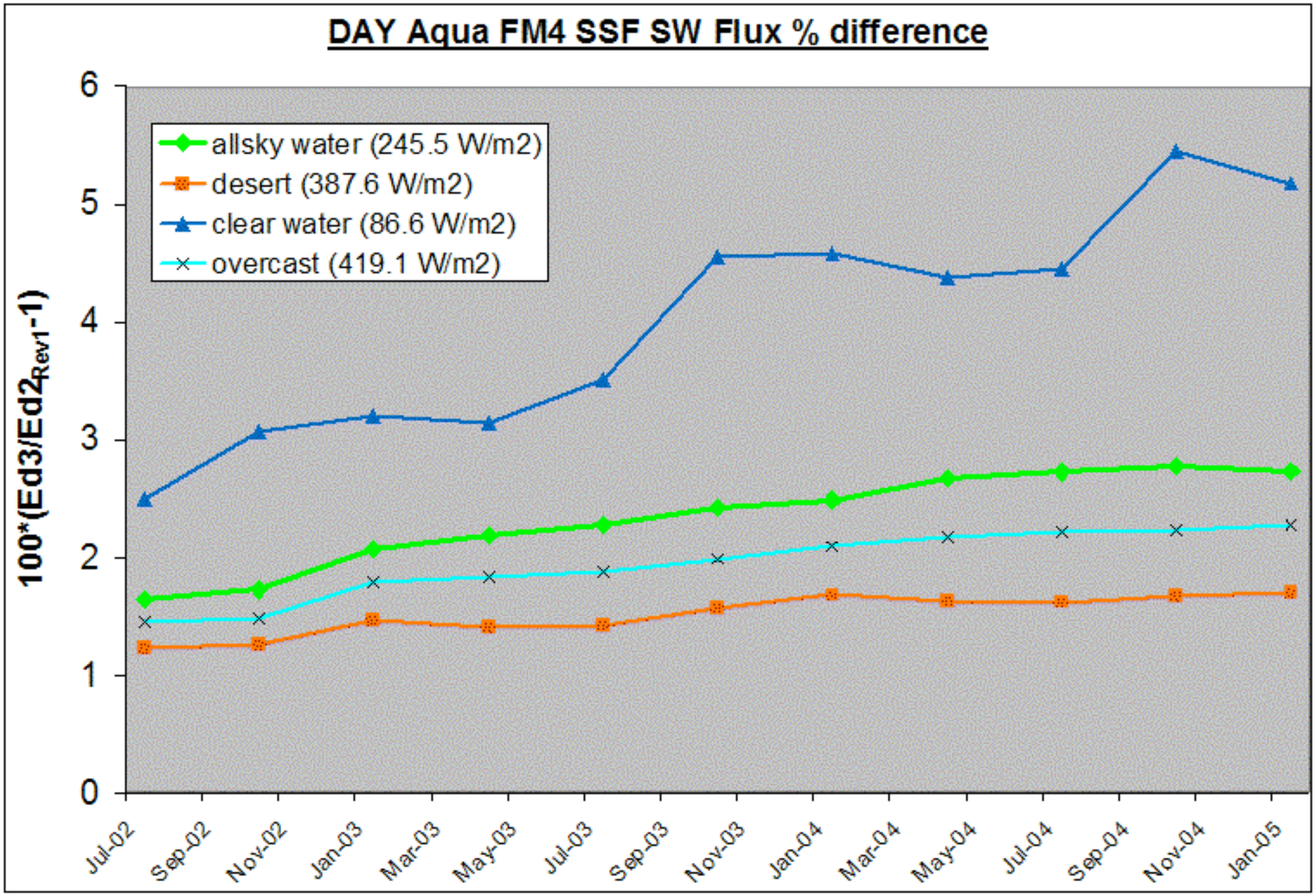
# SSF Edition3 Test run changes from Edition2$_{Rev1}$



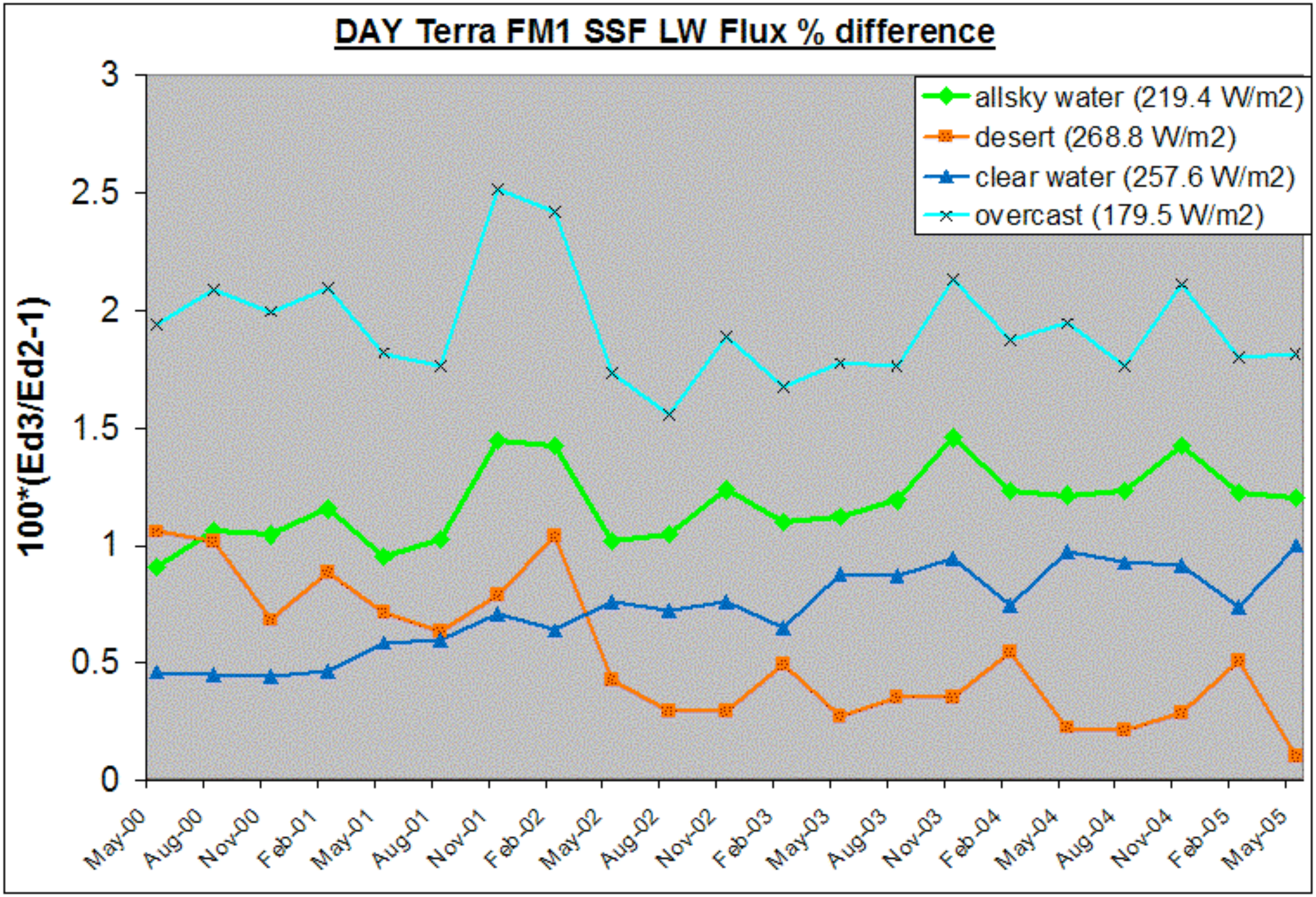
# SSF Edition3 Test run changes from Edition2$_{Rev1}$



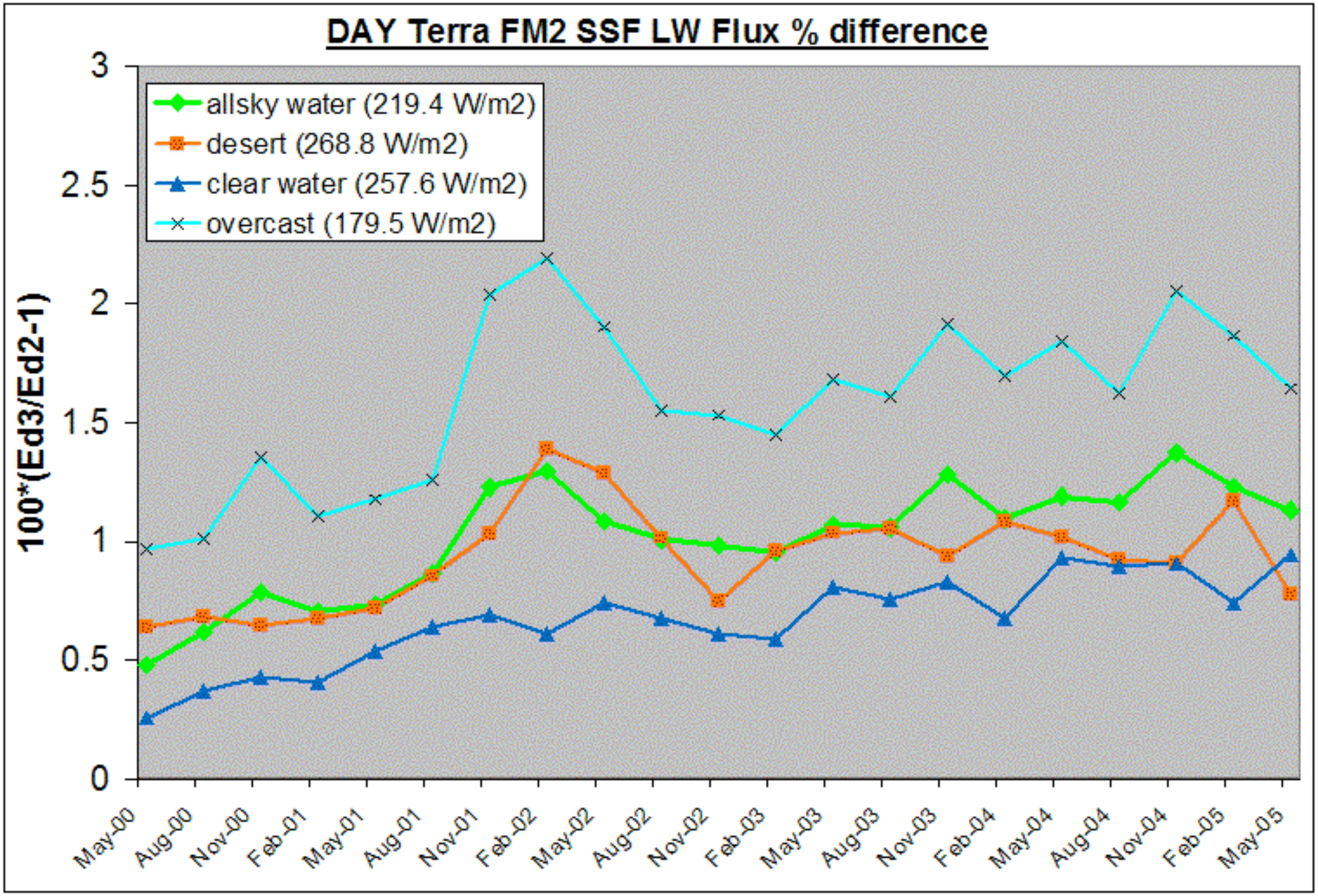
# SSF Edition3 Test run changes from Edition2$_{Rev1}$



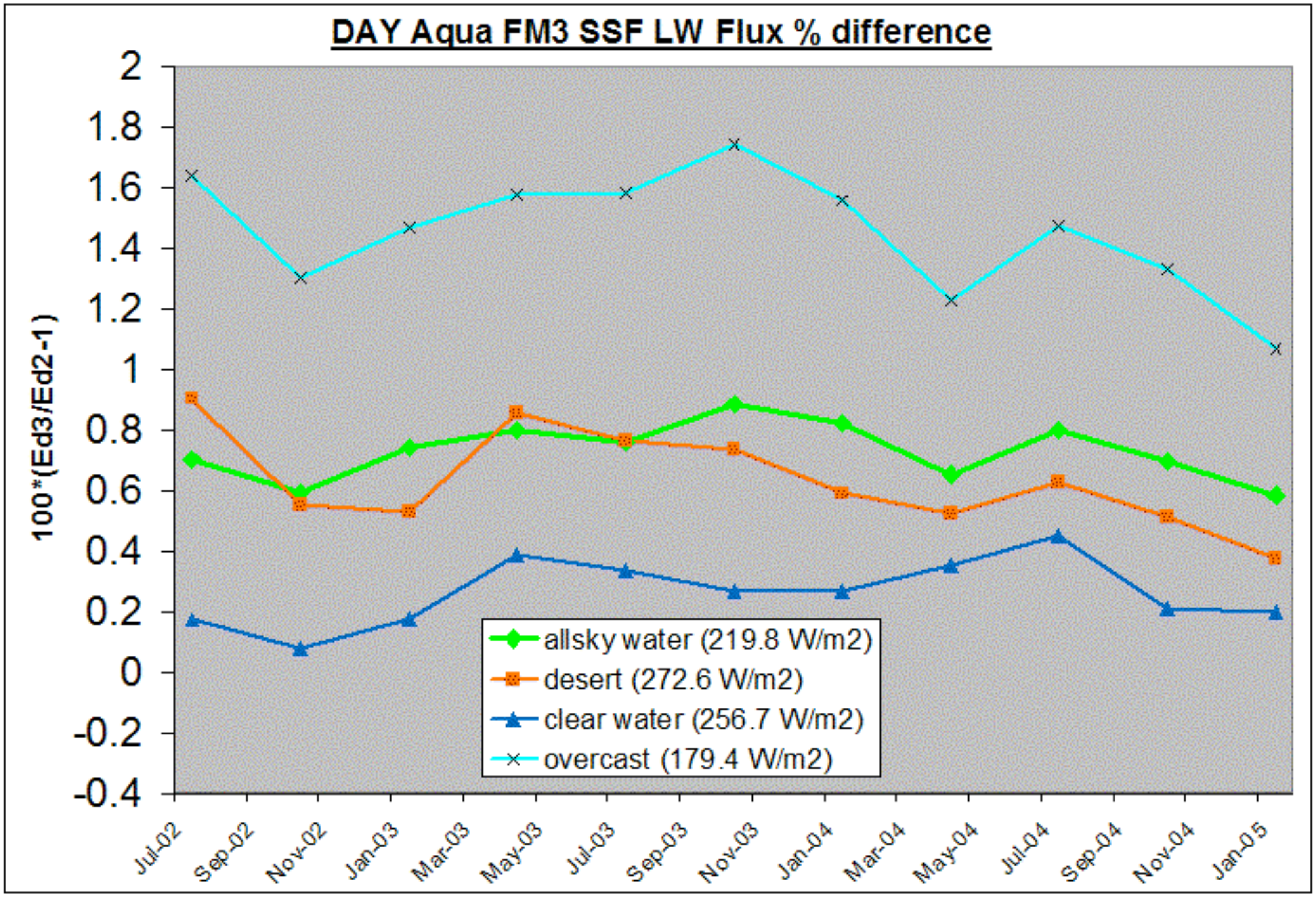
# SSF Edition3 Test run changes from Edition2



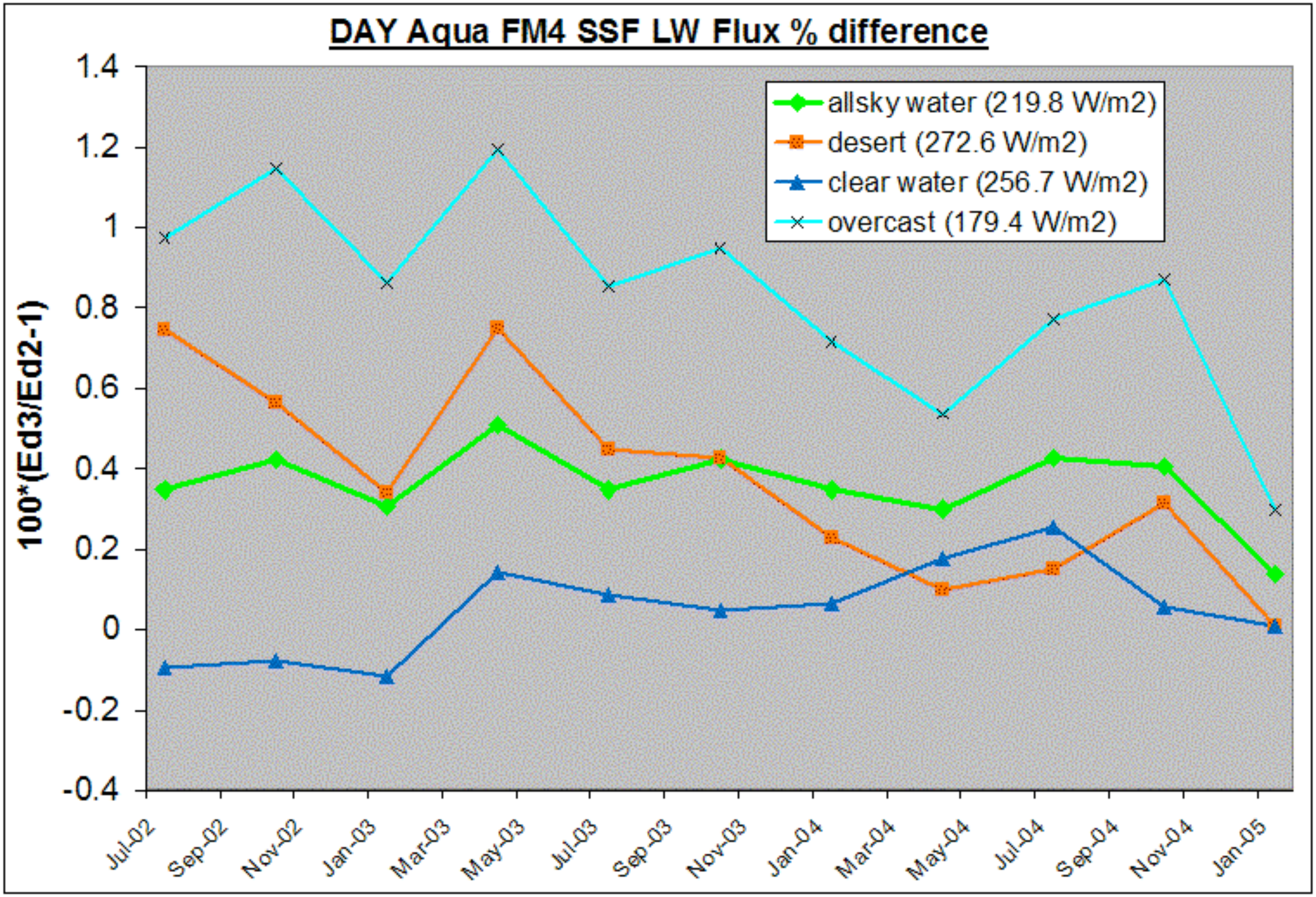
# SSF Edition3 Test run changes from Edition2



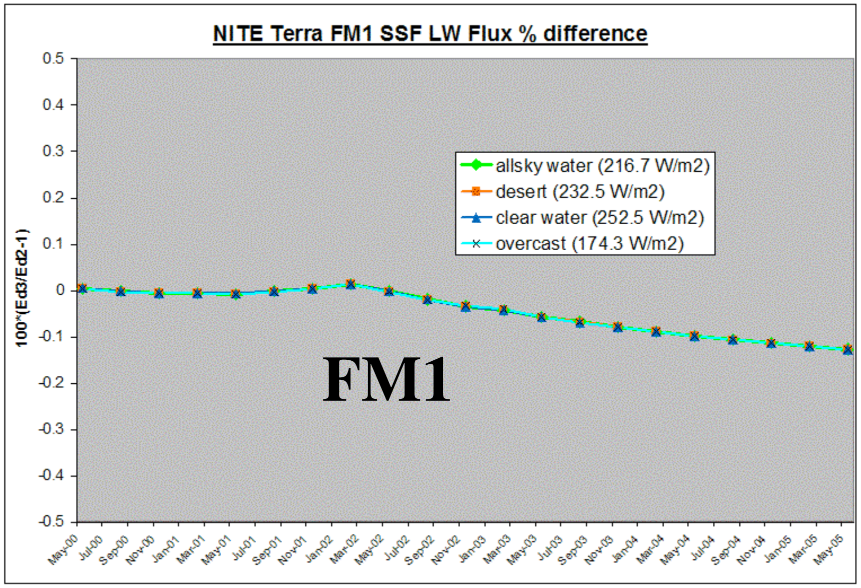
# SSF Edition3 Test run changes from Edition2

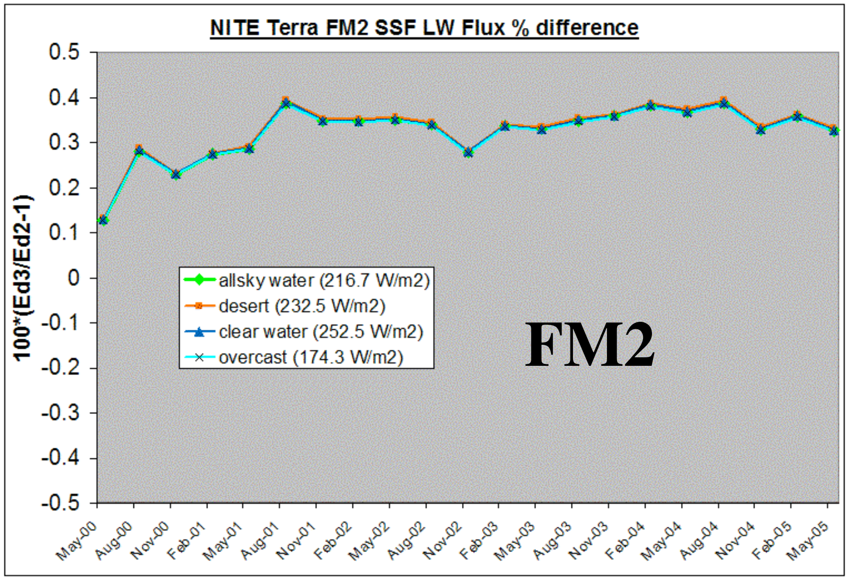


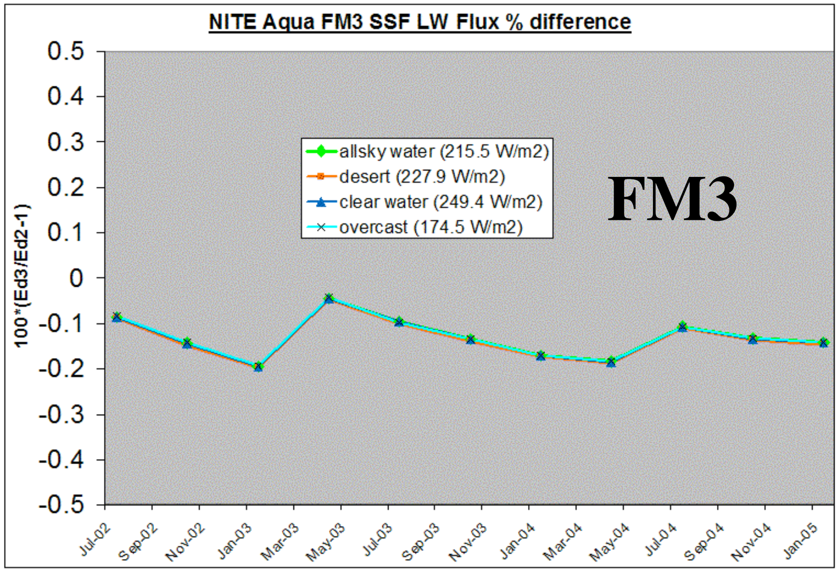
# SSF Edition3 Test run changes from Edition2

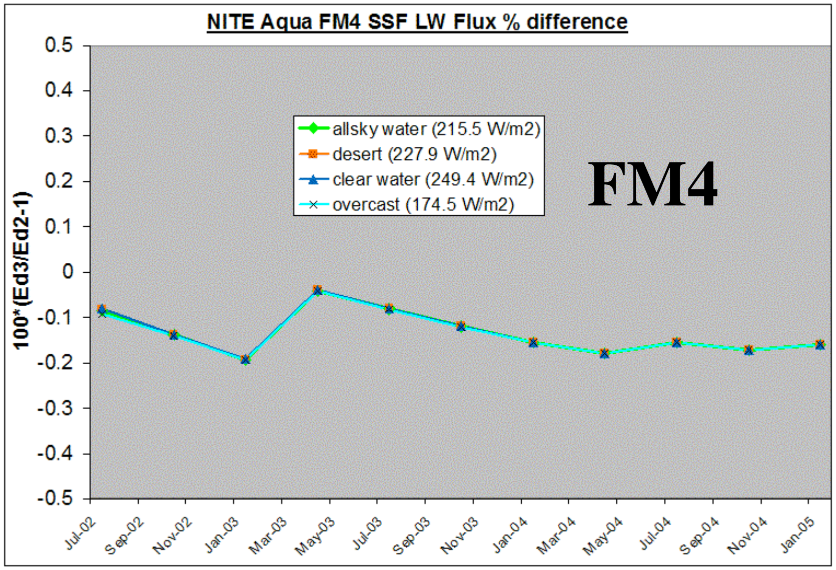


# NITE LW SSF Edition3 Test run changes from Edition2



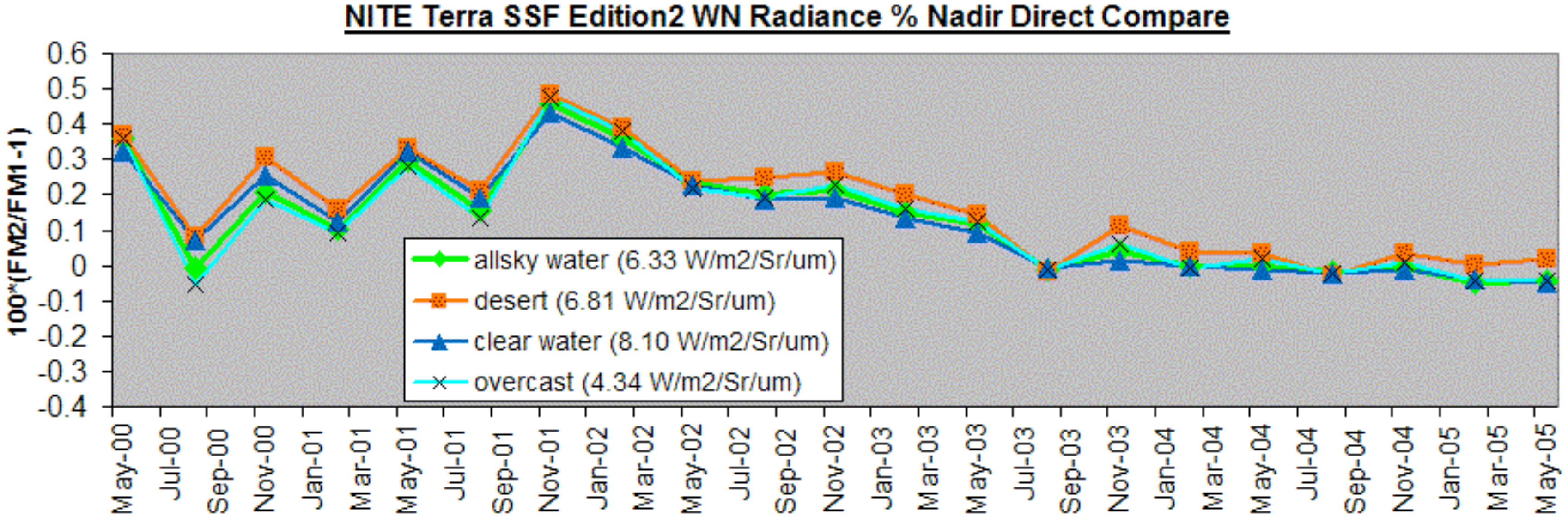



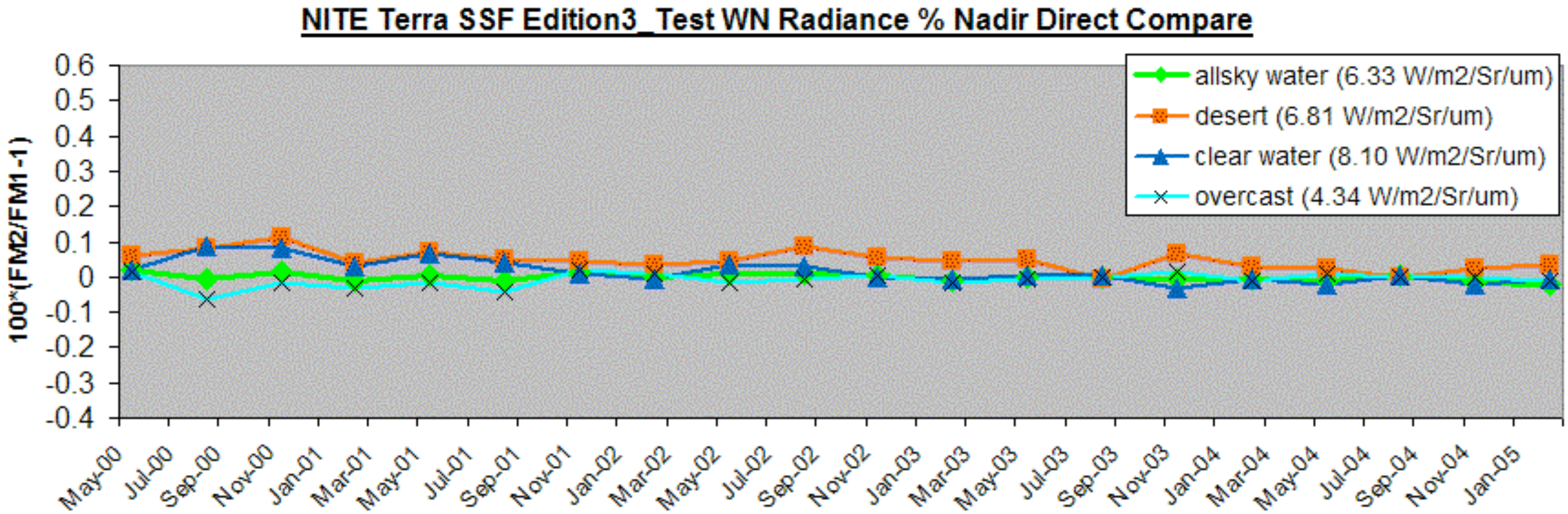



# Summary & Thoughts for Comment

- Improved SW contamination spectral darkening model now produces realistic SW gain and spectral response changes for both Terra and Aqua
- These changes result in the removal of Edition 2 trends in DCC albedo from the Edition 3 test run. **Can DCC albedo change?, SeaWIFS check?**
- They also result in significant reduction in direct compare trends and scene dispersion compared Edition 2
- Terra absolute trend changes comparable to Rev1 within 0.5% while **Aqua Rev1 adjustment appears to be a too small by > 1% ?**
- Terra SW flux increase of +0.4% due to SWICS re-analysis and **using FM1 as reference standard for FM2?**
- Aqua SW flux increase of > 1% using DCC albedo, likely caused by start of mission contamination issues **(FM4 clear ocean +2.5% at start!?)**
- Daytime LW increase: Terra +1% at start and continues to increase by 0.5%, Aqua +0.6% at start with minimal allsky trend
- **Comments? Instrument Working group session for more detail.**

# SSF Edition3 Test run changes from Edition2



# SSF Edition3 Test run changes from Edition2